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ABSTRACT

This background paper focuses on the end point of educational preparation for science and engineering careers--undergraduate and graduate study. It places the issue of the supply of scientists and engineers in the broad cultural context of changing demographics, labor market adjustments, and intervention policies. The first chapter discusses the diversity of students and institutions. The second chapter focuses on undergraduate education, including its importance, students' characteristics, federal roles, and institutional settings. Graduate education is discussed in the next chapter. The nature of graduate study, markets for doctorates, finance, federal support trends, and the future of graduate education are described. The final chapter focuses on engineering education, including the areas of supply and demand, quality issues, use and upgrade of the work force, and roles of the Federal Government. Appendices include: (1) a mathematics intervention project; (2) productivity ratios for 100 undergraduate institutions; (3) graduate education in foreign countries; (4) reports on engineering education; and (5) contractor reports. (YP)

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HIGHER EDUCATION FOR SCIENCE AND ENGINEERING

A BACKGROUND PAPER

MARCH 1989

CONGRESS OF THE UNITED STATES OFFICE OF TECHNOLOGY ASSESSMENT

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PREFACE

This background paper focuses on the end point of educational preparation for science and engineering careers — undergraduate and graduate study. It places the issue of future supply in the broad cultural context of changing demographics, labor market adjustments, and intervention policies. In a dynamic economy and an increasingly technological society, planning is essential. But because of that very dynamism, the flexibility of workers is critical, as is the recognition that some short-term remedies may create longer-term problems.

The demographic trend of greatest significance is that the school-age population, beginning in the 1990s, will look unlike any we have ever seen in this Nation. That makes the future less certain and less predictable. It also warns us to be particularly careful with the extrapolations of the past that show, for example, a poor representation of minorities in these fields. The trend further suggest the need to identify and replicate programs and actions that seem to work, both inside school and out, to bring students into science and engineering and keep them there through completion of degrees.

History has shown that some students have not been well served by formal public education. If we are to bring more of these students into the ranks of scientists and engineers, promising programs are worth trying, even if they are unproven. We need to revise our methods and models of recruitment, clarify the image of "scientist" and "engineer," and rethink the notion of "professional calling" as it relates to the accessibility of the scientific career.

This paper also represents the last leg of an OTA journey begun in 1984 at the request of the Science Policy Task Force of the House Committee on Science and Technology. The first leg, *Demographic trends and the Scientific and Engineering Work Force* (December 1985), warned of the perils of trying to project demand for scientists and engineers.

A followup Staff Paper in January 1987, "Preparing for Science and Engineering Careers: Field-Level Profiles," disaggregated 20 years of enrollment and degree data, by field, sex, and race and ethnicity. This statistical characterization of student flows into science and engineering underscored the need to analyze the process by which students bridge educational aspirations to achievements. In a report published in June 1988, OTA presented such an analysis. *Educating Scientists and Engineers: Grade School to Grad*

School recast the science and engineering pipeline as a kind of permeable membrane that accommodates the recruitment and retention of some students who, for the most part, are undecided about their careers and sensitive to opportunities they perceive in an everchanging job market. Students are buffeted about an education system that succeeds for some yet fails so many others.

These "others" are the very segments of the school-age population from which elementary and secondary education must draw students to interest in, and prepare for, careers in science and engineering. OTA's Technical Memorandum, *Elementary and Secondary Education for Science and Engineering* (December 1988), elaborates the "all one system" theme while examining both formal and informal education in science and mathematics. Clearly, curriculum, teaching, textbooks, and testing are components of schooling. But schools are subject to State and local jurisdictions. Since no one thing works for all children, research on how students learn and how to affect classroom practice now complements the development of out-of-school programs anchored in the community and fortified by a coalition of local business, industry, university, and government support.

The Federal role is catalytic — some say more symbolic and experimental than exemplary — but leadership, most agree, must be exercised at the national level. The purpose of this paper is to analyze, with various data collected in the course of the assessment reflected in *Educating Scientists and Engineers* the distinctive and common characteristics of undergraduate, graduate, and engineering education in the United States. These three topics are addressed in separate chapters, preceded by an introduction that offers a perspective on Federal policies for higher education, and specifically on the processes that transform talented students into productive researchers, innovators, faculty, and administrators.

It may be an axiom of social change, growth, and progress, but people are our most precious commodity. Renewing and developing human resources is a vital underpinning of American society and its competitive position in the world. Whether the goal is an increasingly science and technology literate public, excellence in research and development, a robust economy, or an improved quality of life for all citizens of the Nation, education is arguably the most protracted and therefore powerful experience in our lives. It demands attention.

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Chapter 1

Diversity of Students and Institutions

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Chapter 1

Diversity of Students and Institutions

American colleges and universities prepare undergraduate and graduate students to become the next generation of scientists and engineers. These institutions' immense influence on students' careers, skills, and attitudes determines the size, composition, and quality of the future science and engineering work force. To effect any significant change in this work force will take long-term public policy efforts at all levels of education, and commitment by families, businesses, and communities. Colleges rely on elementary and secondary schools; yet without sufficient academic preparation (particularly in mathematics) and interest in science, children will not be able to succeed in a college major in science or engineering.[1]

Large research universities, small liberal arts colleges, the historically Black institutions, 2-year institutions, and a mix of special-purpose colleges, universities, and technical institutes, public and private, make American higher education highly diverse in size, purpose, and structure. Each type of institution provides a unique environment for developing ability and encouraging persistence. No one environment is suitable for all students (although some institutions produce more scientists and engineers than others). This report looks at these institutions as producers of a future work force, and provides a perspective on fledging scientists and engineers.

STUDENTS AND HIGHER EDUCATION

The quality and diversity of American higher education in all fields is globally respected. Enrollments continue to grow, but demographic trends portend a decline in the number of college-age students in the 1990s, with some increases early in the 21st century. Since demand for scientists and engineers is expected to increase, many policymakers worry that the supply of new graduates will fall significantly short.

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[1] U.S. Congress, Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering*, OTA-SET-TM-41 (Washington, DC: U.S. Government Printing Office, December 1988). While action at the elementary and secondary level will not affect the supply of entry-level and Ph.D. scientists and engineers in the next few years, long-term improvement and expansion of the pool of scientists and engineers must be built on the base of a well-prepared, enthusiastic population of high school graduates.

Universities warn that their aging instructional equipment and facilities hamper their ability to deliver a quality technical education. In addition, as demand for workers in emerging fields outstrips the availability of new graduates, there are continuing mismatches between supply and demand in specialized fields, as well as continuing vexation over the low representation of women and minorities in science and engineering professions.

A strategy to increase the supply and quality of young scientists and engineers must be based on an understanding of the unique problems fostered by demographic change. Such strategies should include *recruiting* more students into science and engineering majors, particularly the undertapped resources of women and minorities; *retaining* more of these through higher degrees and into technical careers; and *bolstering* the college and university infrastructure for instruction and research. Special programs that prepare students, provide them with academic and social support, and involve them in hands-on research, help keep students in science.

A robust job market reflects a robust economy, which, in turn, powers Federal and national research and development (R&D) spending and boosts student recruitment and retention.[2] Undergraduate financial aid has created a substantial pool of college students from which science and engineering, among other fields, have drawn talent. Institutions of higher education can do more, as reflected in the many initiatives of individual colleges and universities, as well as in programs sponsored by industry and professional societies.[3]

Many students come to science and engineering *during* college, not before. A national study showed that 20 percent of science/engineering majors had not planned science or engineering majors during high school. More might enter if they were not stymied by the relative rigidity of most science and engineering curricula, which demand early commitment to a sequence of courses, particularly in mathematics.[4] The flexibility of student interest indicates that science and engineering programs could seek out students as late as their sophomore or even junior years of college, and that colleges could help by providing administrative and curricular gateways for students to change majors and "catch up."

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[2] For an elaboration on these and the policy options summarized below, see U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School*, OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988), esp. ch. 4.

[3] For example, see Elaine El-Khawas, *Campus Trends, 1988*, Higher Education Panel Report Number 77 (Washington, DC: American Council on Education, September 1988).

[4] Valerie E. Lee, "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition," OTA contractor report, 1987. Based on the High School & Beyond survey, following high school sophomores of 1980 through their college sophomore year (1984). Many of the findings reported here derive from analyses

At the graduate level, putting money into U.S. research universities — through research grants, research and teaching assistantships, fellowships, and traineeships — has proved a relatively straightforward mechanism for increasing the supply of quality Ph.D.s. Targeted financial aid, mostly research training subsidies for graduate students, enables students interested in research careers to pursue the lengthy training required, and may even attract more students. Upgrading the capacity for graduate education is a costly and long-term endeavor; even large, elite institutions require continuing support to maintain the quality of their research and education programs.[5]

Unlike elementary and secondary schooling, higher education in the sciences and engineering is subject to direct Federal influence. About 13 percent of the $60 billion dollars spent annually by all levels of government on higher education comes from the Federal Government. Federal funding is particularly important at the graduate level, where Federal fellowships and other forms of assistance are awarded to support specific graduate students in specific fields of study, and where the majority of academic research is supported by Federal funds. Federal R&D programs are also highly influential in graduate education since they provide employment opportunities for researchers in universities, industry, and government, and thus heighten the attraction of graduate research training.

ORGANIZATION OF THIS REPORT

This report is presented in three chapters: undergraduate, graduate, and engineering education. This reflects divisions both in the organization of the higher education enterprise and in the policy actions relevant to each.[6]

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performed in 1987 as part of the assessment that led to Office of Technology Assessment, op. cit., footnote 2. In some cases, databases have been updated; for most of OTA's results, the terminal data point is 1986, though some enrollment and degree data extend to 1987.

[5] Arthur M. Hauptman, "Higher Education May Face an Era of Retrenchment No Matter Which Candidate Is Elected in November," *The Chronicle of Higher Education*, Oct. 19, 1988, p. A52.

[6] This report was neither conceived nor written as a policy document. It contains no

Undergraduate education has traditionally been characterized by diversity, with several thousand colleges and universities pursuing very different missions and student bodies. The Federal role has been one of providing financial support to ensure individuals educational opportunity; a concern for equity has set the policy tone.[7] Federal science-related programs for undergraduate research, faculty, and institutions have been limited in extent but potent in effect. That is, specific fields have seldom been singled out for Federal support.

Graduate education has long been an area of direct Federal action, because of the national need for Ph.D.-trained scientists and engineers. Extensive Federal subsidies of graduate education and university research have strongly shaped the nature and extent of graduate education, and the supply of science and engineering Ph.D.s.[8]

Educating engineers differs from educating research- and academically-oriented scientists; the vast majority of engineers work in industry, and can seek a relatively high-paying professional job with a bachelor's or master's degree rather than a Ph.D. (A strong baccalaureate market exists for physicists, chemists, and computer scientists as well, so the similarities between the entry-level destinations of some scientists and engineers belies the general differences in their undergraduate preparation.) The national attention to manufacturing and technological competitiveness augurs an increasing Federal interest in the quality of engineering education.

Undergraduate Education

The Federal Government has been instrumental in expanding access to college. Financial aid in all forms, including the G.I. Bill, has helped many low- and middle-

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single policy section or chapter. Rather, it is an education research report with a devotion to data and an eye on what they might mean for the members of various communities, including policymakers. For a recent example of a similar document written from an academic perspective, see Richard J. Shavelson, "Contributions of Educational Research to Policy and Practice: Constructing, Challenging, Changing Cognition," *Educational Researcher*, vol. 17, October 1988, pp. 4-11, 22.

[7] Kathryn Mohrman, "Unintended Consequences of Federal Student Aid Policies," *The Brookings Review*, vol. 5, No. 4, fall 1987, pp. 24-30.

[8] For a review of Federal legislation in fiscal years 1988 and 1989 geared to science and engineering education, see U.S. Congress, Congressional Research Service, *Major Legislation of the Congress*, Issue No. 3 (Washington, DC: U.S. Government Printing Office, August 1988), pp. MLC-021, MLC-102; and U.S. Congress, Congressional Research Service, "Education: The Challenges," *Congressional Research Service Review*, vol. 9, No. 9, October 1988.

income students attend and complete colleges; scholarships have been particularly effective. Science and engineering undergraduates are similar to other students in their use of aid, and loan burdens do not seem to affect students' choice of major or decision to attend graduate school. The vast majority of aid has been given solely on the basis of need, without regard to the interests of the students or the institution they are going to attend. Educators have suggested creating a scholarship (based on merit and/or need) for undergraduates majoring in areas of national need, such as science and engineering. Although this diverges from conventional policy wisdom, there is precedent in special scholarships for future teachers. Such a program would likely encourage some students to pursue targeted fields, although the extent and effect of such a program is uncertain.

The abundance of college-educated students has benefited all professions, including science and engineering. The level of college enrollments is important to the supply of scientists and engineers, who have in the aggregate maintained for more than 3 decades a fairly steady 30 percent share of all baccalaureates (20 percent for natural science and engineering). However, there have been significant shifts in the distribution of students among fields within science and engineering, reflecting undergraduates' changing interests as well as the job market. The social sciences, and to a lesser extent the physical and biological sciences, have experienced steady declines, while engineering and computer science have been rising in popularity (until very recently). Science and engineering majors continue to attract a high proportion of academically able students.[9]

Another perspective on the future supply of scientists and engineers centers on the phenomenon of attrition. Fewer than half of freshman science and engineering majors complete a baccalaureate in science and engineering. However, some peer and academic support programs have been effective in helping students complete their chosen majors. Such programs are being widely publicized, expanded, and replicated.[10] In the long run, however, efforts to reduce attrition or attract new talent will collapse unless students perceive career opportunities in research, teaching, and practice. Unless job markets are strong, increasing the output of scientists and engineers will result only in underemployment and frustration. Strong job markets in academic research and teaching, as well as Federal, State, and industrial R&D initiatives, can elevate enrollments, although spot shortages and surpluses at disciplinary and subdisciplinary levels are to be expected in a dynamic economy.

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[9] Kenneth C. Green, University of California, Los Angeles, personal communication, 1987.

[10] Edward B. Fiske, "Accountability Looms as the Watchword of the 90s in Higher Education," *New York Times Education*, Nov. 16, 1988, p. B8.

The quality of undergraduate education is at least as important as the number of degrees. Of course, quality is notoriously difficult to define or to package in a policy initiative. Often-cited indicators of quality are well-prepared students committed to learning and helping each other learn; faculty and teaching assistants who enjoy and are rewarded for teaching; thoughtful, interactive curricula; well-maintained equipment and facilities for students to experience "real-life" bench research; and time and money for students to immerse themselves in full-time study. Experiencing research as an undergraduate is one of the most effective means of luring students to a career in science (or helping them discover early that they are not suited for such a career).[11] The National Science Foundation has designed many small but effective programs to improve quality. Federal mission agencies also have programs; and there is much scattered activity within individual institutions, industry, local companies, professional societies, and some States.

Some colleges have particular success in sending their graduates on to Ph.D.s in science and engineering. These nurturing environments are particularly important for women and minority students. The characteristics of these environments are individual attention to student development, undergraduate research participation, and a commitment to quality teaching. Such characteristics can be replicated. Federal policies can help institutions improve the quality of instruction with funding and incentives for undergraduate research, cooperative education, instruction and laboratory equipment and facilities, and faculty and institutional development. Nevertheless, it helps to start with bright, motivated students, and then invest in them.

Graduate Education

As students weigh graduate study and a research career, they consider both economic and noneconomic factors. Salary is one consideration among many in the career choices of aspiring academic researchers. The expectation of a rewarding research career is high on a list that includes the traditional rewards of university research: intellectual freedom, security of tenure, and the creative challenges and social pleasures found in the university environment.[12] Even so, a small fraction of baccalaureate-level scientists and engineers elect to pursue science or engineering doctorates at more than 330 institutions.

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[11] Janet Lanza, "Whys and Hows of Undergraduate Research," *BioScience*, vol. 38, No. 2, February 1988, pp. 110-112.

Most fields of study in the sciences, as distinguished from engineering, are oriented toward the academic job market, even though only one-half of all scientists work in academic institutions. The Ph.D. is the entry professional degree in these fields. Since the early 1970s, however, the academic job market in many fields has stagnated, as growth in undergraduate enrollments has slowed. Graduate enrollments have been sustained largely by foreign students who have helped compensate for the decline in enrollments by U.S. citizens.

Strategies to increase the number of American graduate students focus on bringing more women and minorities into engineering. While the participation of women in engineering increased rapidly during the late 1970s, it seems to have plateaued. A "chilly climate" still prevails on campus. Role models are too few, and access to career opportunities and salaries are still perceived as gender-linked in science and engineering, perhaps even more so than in business or law.[13]

The environment in which graduate study and academic research takes place is undergoing structural change, which may affect the attractiveness of research as a potential career. In the past two decades, an emphasis on applied research has transformed universities' mission; undergraduate teaching and basic research have suffered. The faculty turnover expected in the 1990s, as the postwar generation of faculty retires, may present an opportunity to renew the commitment to teaching as fundamental to the academic enterprise.[14] Unfortunately, the research university does not seem to value teaching and "community service" as much as research (grant-getting and publishing). And this reward system seems largely impervious to change.

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12. Alan Porter et al., "The Role of the Dissertation in Scientific Careers," *American Scientist*, vol. 70, September-October 1982, pp. 475-481.
13. Nadya Aisenberg and Mona Harrington, "A 2-Tier Faculty System Reflects Old Social Rules That Restrict Women's Professional Development," *The Chronicle of Higher Education*, Oct. 26, 1988, p. A56; and Roberta M. Hall and Bernice R. Sandler, *Out of the Classroom: A Chilly Climate for Women?* (Washington, DC: Association of American Colleges, Project on the Status and Education of Women, October 1984).
14. Betty M. Vetter, "Replacing Science and Engineering Faculty in the 1990s," presented at the Conference on Undergraduate Research, Carlton College, Northfield, MN, July 13, 1988.

Engineering Education

The supply of engineers is of widespread concern because of the pivotal role that engineers play both in research and in bringing new technological developments into production and the global market. Increasingly rapid technological progress shortens the half-life of engineering knowledge, as educators struggle to keep apace with the demand for engineers freshly trained in the latest theories and techniques.

Because students are sensitive to the current job market rather than opportunities awaiting them when they graduate, the supply of new graduates is often mismatched to demand. There are shortages in some specialties, which stem from rapid growth in demand (and lags in supply response). Such transitory shortages seem unavoidable. Because of these shifts and mismatches, maintaining a strong enrollment base is important. Overall, the supply of engineers appears adequate. However, student interest in engineering is declining slightly, reflecting a softening of the job market relative to the market-driven boom in the late 1970s, as well as what some sense is a deeper malaise.[15]

Options for increasing the supply of engineers include both retraining and upgrading the education of technicians and technologists. Retraining of engineers in oversubscribed specialties, and of engineers in nonengineering jobs such as management, can help meet changing demand. Retraining, like other strategies, however, is not cost-free. New information education technologies, particularly video and satellite-based systems, which can cheaply and quickly reach engineers or technicians at their workplace, can help boost the supply and quality of engineers through retraining.[16]

A prominent issue in engineering is the large and growing presence at the graduate level of foreign students. Over one-half of graduate students are foreign. This is due, most believe, to the relative lack of interest on the part of American students in pursuing low-paying graduate study; the costs incurred and salary foregone is not perceived as worth the entry-level pay in academia. Instead, Americans seek lucrative,

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15. "For Engineers, 4 Years' College Not Enough, Says MIT Dean," *Engineering Times*, December 1988, p. 5; and "Engineering Curricula to Get NSF-Funded Revamps," *Engineering Times*, December 1988, p. 5.

16. National Research Council, *The Effects on Quality of Adjustments in Engineering Labor Markets* (Washington, DC: National Academy Press, 1988). Attracting scientists from nearby disciplines and keeping more active engineers from leaving the profession are related strategies for ensuring the future supply of engineers.

interesting positions in industry working with the latest equipment. About one-half of these foreign graduate students in engineering stay on in the United States in academia and industry. They make enormous contributions as graduate students and later as full-fledged engineers and researchers.

Controversy, however, arises in several areas. Although foreign students are widely regarded as competent researchers, many come with poor English and cultural biases which detract from their effectiveness as teaching assistants and colleagues. In response, universities have established English language requirements and courses to help acculturate foreign graduate students.[17]

In the absence of modifications in immigration policy and visa status, the proportion of foreign graduate students will continue to haunt some employers recruiting engineers for defense-related projects. Most such projects are open only to U.S. citizens. Some argue that, given the great benefits of foreign engineers to U.S. universities and industry, the United States should encourage not only students on temporary visas but also their eventual permanent immigration. On the other hand, there is some insecurity in relying on foreign students for critical knowledge (especially those on temporary visas who might unexpectedly return home). A corollary problem is the "draining" of highly-educated people from their native countries. Foreign engineers (and scientists) have been an invaluable source of talent in the past, and encouraging study and immigration does not preclude trying to increase the interest of U.S. students in engineering.

The number of U.S. engineering Ph.D.s increased slightly in 1986 and again in 1987, and graduate enrollments are rising; these figures, however, follow a long decline. Most proposals to attract more American students start with increasing pay for graduate students, so that stipends are at least one-half of what a baccalaureate could earn in industry. During the early 1980s, the years of strongest recent demand for engineers, some universities created special pay scales to recruit and retain engineering faculty; these seem to have helped.

The participation of Blacks and Hispanics in engineering, as well as the physical sciences, shows little sign of substantial increase. (Asian-Americans, on the other hand, are more likely than whites to major in engineering and go on to graduate study.)

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[17] National Research Council, *Foreign and Foreign-Born Engineers in the United States: Infusing Talent, Raising Issues* (Washington, DC: National Academy Press, 1988).

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Although special programs at all levels of education have spurred extraordinary increases in Black and Hispanic students' interest in engineering, Blacks are still more than twice as likely as whites to drop out of an engineering major. Programs such as California's Minority Engineering Program, which has tripled participants' likelihood of persisting to a degree in engineering, succeed in retaining students in the pipeline.[18]

While leadership must come from university faculty and administration, external aid can make a difference. That aid can be money, but it also can be equipment and staff loans. The Federal Government can also assist by publicizing intervention programs, as well as sponsoring, evaluating, and replicating successful ones.

Cooperative education and other engineering-related work experience is valuable, too, but is neither widespread nor well institutionalized. The Federal Government employs many "co-op" students, and can give students access to unique work opportunities in Federal laboratories. In the 1970s, Federal funding for cooperative education expanded university programs; in the wake of decreased funding, new incentives for business and industry participation will be needed to create opportunities for students to pursue cooperative education.

Federal programs for engineering faculty, including research and young investigator support, industry-university exchange programs to bring industry engineers into academia, and engineering curriculum development, all enhance the quality of faculty and the education they deliver.

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[18] Raymond B. Landis, *Academic Gamesmanship: Becoming a "Master" Engineering Student* (New York, NY: National Action Council for Minorities in Engineering, 1987).

Chapter 2

Undergraduates in Science

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Chapter 2

Undergraduates in Science

THE IMPORTANCE OF UNDERGRADUATE EDUCATION

A 4-year college degree is the first step toward a career in science or engineering.[1] For future scientists, college provides an education in the fundamentals of science and engineering, as well as experiences that help them to choose an appropriate career direction.

The undergraduate years are critical in shaping students' career plans. During college, most students decide on a particular field of study, and whether to go immediately to graduate school or look for a job. Students' experiences in and out of the classroom combine with their perceptions of the job market to steer them toward or away from particular majors. Many students enter college with broad plans — medicine, engineering, or biology — but rarely with a commitment to a specific career, such as academic research in virology. For example, the typical high school graduate interested in engineering may take some courses in mechanical engineering as a freshman, and then develop a specific interest in designing satellite steering mechanisms.

The quality of education students receive depends upon the resources, priorities, curricula, staff, fellow students, and ethos of the college they attend — the entire institutional environment. Given the preparation of entering students, colleges determine how many students graduate with science or engineering degrees, and the quality of their preparation for graduate school and entry to the work force.

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1. Nearly all scientists and engineers enter and graduate from 4-year colleges. However, over one-half of the 3,300 institutions of higher education are 2-year, or community, colleges. Community colleges fill two major roles related to science and engineering: training technicians and continuing education. Two-year institutions are an important source of technicians and technologists, who are a vital part of the research work force. Another role of community colleges is to help students "catch up" and transfer to 4-year institutions. Although not a significant source of baccalaureate level scientists, many 2-year institutions feed talent to engineering colleges. Unless otherwise noted in this chapter, colleges and universities refer to institutions that award at least the baccalaureate degree. See Cheryl Fields, "Community Colleges Discover They are at the Right Place at the Right Time," *Governing*, February 1988, pp. 30-35.

The Supply of College-Level Science and Engineering Students

American higher education attracts and educates an ample supply of potential scientists and engineers. Over a million new students enter 4-year colleges each year. Over one-third of these freshmen are interested in science and engineering. And despite the large proportion of students abandoning technical majors during college, U.S. colleges and universities graduate large numbers of baccalaureate scientists and engineers each year. Natural science and engineering (NSE) have maintained a steady share among baccalaureate degrees, around 20 percent (with ups and downs in various fields) (see figure 2-1).

Students respond well to changing demand in the labor market, for science or engineering as well as other fields. For instance, the late-1970s' boom in engineering and computer science jobs powered a large, rapid increase in engineering enrollments among new freshmen as well as students already in college. Several disquieting trends, however, now challenge the assumption that this baccalaureate largess will continue. By far the most important, the number of college-age youths in America is dropping and will hit its lowest point around 1996, with modest increases expected early in the next century. Most observers anticipate that this foreshadows a substantial dip in college enrollments, with science and engineering suffering a proportionate drop. This decline might be compensated in part by aggressive college recruiting of women, members of racial and ethnic minorities, and the physically handicapped, and, in part, by increasing general interest in science and engineering (see box 2-A). However, rising student interest in high-paying business careers and the historic low participation of minorities and women in science bode ill for this strategy. Equity of access to college in general and to science and engineering majors in particular remain contentious issues in practice, if not in principle.[2]

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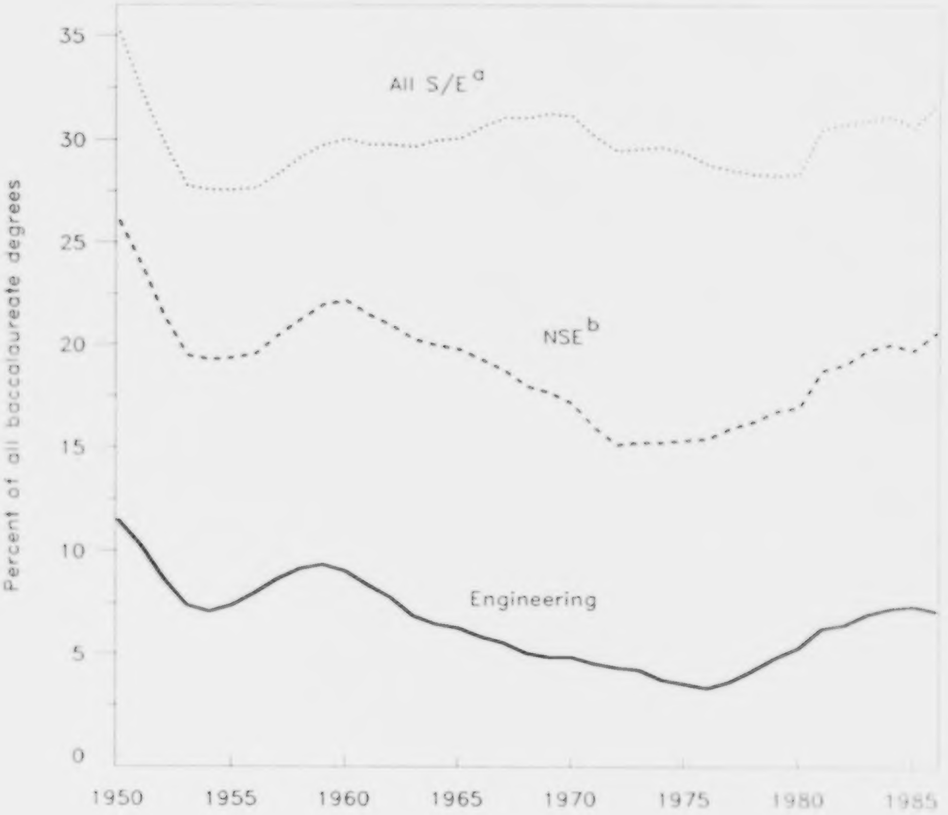
[2] A host of factors — test scores, grades, extracurricular activities, teacher recommendations, student interviews — are weighed by colleges to predict freshmen performance and make admission decisions. The use of standardized tests, the SAT and ACT, has been controversial. Critics claim that these tests, normed to the national population of college-bound high school seniors, contain systematic biases against all but white males. The issue is not the test scores themselves but how they are used in admissions. A recent report, based on interviews and surveys at seven institutions that no longer require standardized tests for admission, shows that applications have increased with announcement of the new policies. See National Center for Fair and Open Testing, *Beyond Standardized Tests: Admissions Alternatives That Work* (Cambridge, MA: FairTest, 1987). Also see Elizabeth Greene, "SAT Scores Fail to Help Admission Officers Make Better Decisions, Analysts Contend," *The Chronicle of Higher Education.* July 27, 1988, p. A20.

Figure 2-1.—Science/Engineering as Percent of All Baccalaureate Degrees, 1950-86



KEY: S/E = science/engineering.
NSE = natural science and engineering.

[a] Includes the social sciences.
[b] Includes engineering and the physical, life, mathematical, and computer sciences, but not social sciences.

SOURCE: Betty M. Vetter and Henry Hertzfeld, "Federal Funding of Science and Engineering Education: Effect on Output of Scientists and Engineers, 1945-1985," OTA contractor report, 1987, based on U.S. Department of Education data.

2

The near-term irreversibility of demographic trends and increased "competition" among careers and curricula for students raise several concerns about the ability of undergraduate institutions to continue to produce a well-prepared supply of baccalaureate scientists and engineers. Such concerns include:

- the factors influencing undergraduates' decisions to major in science or engineering, and the factors attracting or discouraging them from pursuing these fields;
- the access to college and to technical majors for students of all backgrounds, for women and men, for Blacks, Hispanics, and Asians as well as whites (ensuring a broad enrollment base);
- the ability of colleges and universities to provide a high-quality and appropriate undergraduate education for students pursuing technical jobs or graduate study; and
- the effects of the labor market, Federal policies, and college experiences on students' decisions to seek careers in science or engineering.

This chapter looks at each of these areas in turn, focusing on the Federal role in each.

Student Interest in Science and Engineering

The many motivations underlying the choice of college and major are not well understood[3] (see table 2-1). Students develop interests early; many science and engineering students do so before high school. These interests reflect many factors, including innate aptitude, experiences in and outside of school, and the combined influences of family, friends, teachers, and society.[4]

In the aggregate, students' early intentions predict actual college enrollments and declaration of career plans (although individual plans often shift). Students who are

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[3] See U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School*, OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988), pp. 23-25, 33-34.

[4] Factors affecting the development of students' interest in science and engineering, and their preparation for college-level science and engineering, are discussed in U.S. Congress, Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering*, SET-TM-41 (Washington, DC: U.S. Government Printing Office, December 1988).

Table 2-1.-Factors Affecting Undergraduates' Choice of a Science or Engineering Major

Most students have decided on a major by the time they enter college. Innate interest, school experiences, and teacher influences play a large role. Demographic factors, particularly socioeconomic advantages, parents' backgrounds, and education and career values associated with certain ethnic groups, confer preferences that are difficult to affect through policy. However, there is substantial readjustment during the college years, as students tackle college-level courses, encounter new subjects, and face the prospect of earning a living. Many students leave science or engineering altogether; some shift among the sciences; and a few enter from nontechnical majors. Various factors during the college years encourage students to enter or stay in science or engineering.

Factors that attract students:

- Job market for scientists and engineers
- Academic preparation and achievement in high school (particularly including coursework in mathematics; science and computer coursework are also important)

Factors that reduce attrition (and improve the chances of college graduation in any field, not just in science or engineering):

- University attention to student completion ("institutional nurturing")
- Intervention programs and peer support
- Research participation
- Good teaching
- Financial support
- Part-time work or cooperative study

SOURCE: Office of Technology Assessment, 1988.

interested in science and engineering early on in high school are more likely to stay with and graduate in science or engineering.[5] Similarly, freshmen plans, in the aggregate, have foreshadowed the supply of baccalaureate scientists and engineers in various fields 4 years later.[6] Most science and engineering baccalaureates had a serious interest in these fields by the time they completed high school, although many changed majors during college. While students still enter the science and engineering pipeline during the first 2 years of college, the entry gate is closed for most midway through college because of the need to choose among courses for any given major.

Entering freshmen also take note of the current job market.[7] Salary and job opportunity trends are good lead indicators; rapid rises in starting salaries suggest a shortage, and students usually respond. Since salaries rarely go down, adequate supplies or surpluses are usually indicated by little or no real growth in salaries.[8]

The influence of Federal policies on undergraduate student interest is remote and indirect, limited mostly to influence on the job market for scientists and engineers and high-visibility research and development (R&D) initiatives. While Federal student aid is instrumental in getting students into college, such aid is given irrespective of major and does not influence students' choice of field.

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5. Kathleen G. Sparrow, "A Profile Differentiating Female College Science Majors From Nonscience Majors: A Predictor Set of Variables," presented at the National Convention of the National Association for Research in Science Teaching, Washington, DC, April 1987.
6. Trend data on B.S. awards and freshmen interest illustrate this relationship. One example is freshmen interest in engineering in the early 1970s. This was a period of upheaval for technical personnel: in addition to the shutdown of Apollo, Congress had decided not to fund supersonic transport development, defense contracts were declining, and large numbers of engineers in areas near major aerospace contractors such as Boeing, Hughes, and Lockheed were out looking for work. As the job market for engineers began to recover in the mid-1970s, so too did freshmen interest in engineering majors. The increase in engineering degree awards in the late 1970s correlates almost perfectly with the trends in freshmen majors in survey data 4 years earlier (see Kenneth C. Green, University of California, Los Angeles, personal communication, 1987). The downturn in freshmen interest in engineering majors and careers that began in 1982 should manifest itself in the last years of the 1980s (indeed, the most recent data show a slight decrease in engineering degree awards).
7. U.S. Congress, Office of Technology Assessment, *Demographic Trends and the Scientific and Engineering Work Force*, OTA-TM-SET-35 (Washington, DC: U.S. Government Printing Office, December 1985), pp. 34-40.
8. Nestor E. Terleckyj, "Employment of Natural Scientists and Engineers: Recent Trends and Prospects," presented at the Workshop on the Prospective and Expected Economic Effects of the Changing Age Structure of the U.S. Population, National Science Foundation, Washington, DC, July 1987.

Changes in social values also affect students' career plans. According to surveys, students of the 1980s increasingly value high salaries, career advancement, professional reputation, and comfortable lifestyles, and place far less importance on community and environmental activism and self-exploration than did students in the 1960s.[9] Majors leading to highly-paid, visible careers have grown the fastest. Within the sciences, engineering and computer science majors have grown, while social science majors have dwindled.

Information on entering college students, and their eventual college performance and degrees, can help describe who chooses and stays with science. A large proportion of entering freshman are interested in science and engineering majors. Among incoming full-time freshman in 4-year institutions, about one-quarter plan to major in NSE, and slightly over 30 percent over all science and engineering fields.[10]

However, student preferences have shifted away from science. The share of incoming college freshmen interested in NSE has declined slightly, from 27 percent of first-time, full-time freshmen in 1978, to 24 percent in 1986. During that same period, interest in all of science and engineering, including the social sciences, declined from 37 percent to 34 percent.[11] Figure 2-2 shows the 1977-87 trend in planned majors among freshmen at 2- and 4- year institutions.[12]

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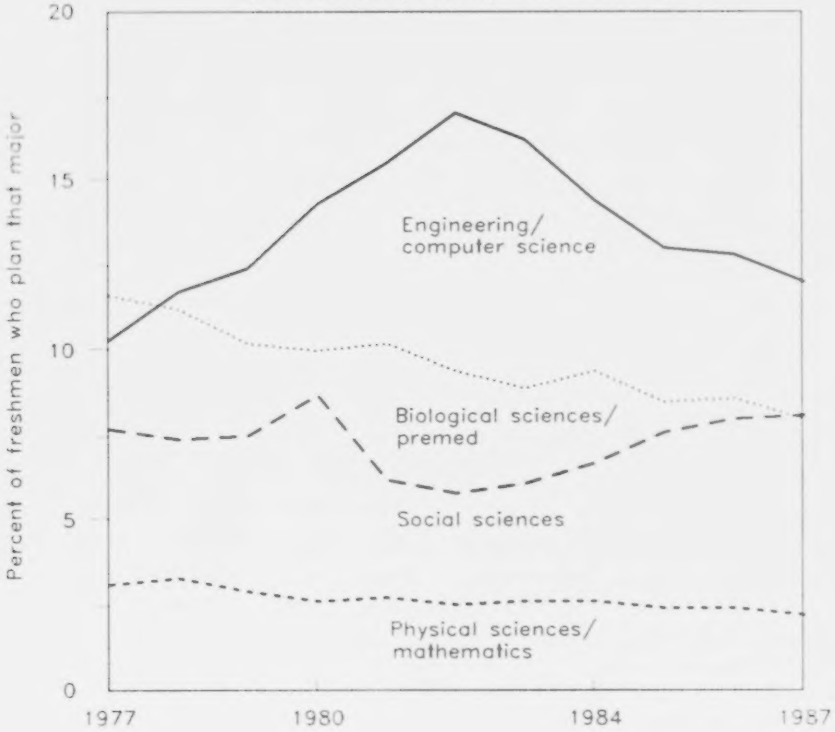
[9] Alexander W. Astin et al., *The American Freshman: Twenty Year Trends 1966-1985* (Los Angeles, CA: University of California at Los Angeles, Cooperative Institutional Research Program, January 1987), pp. 14-26, 97.

[10] The more restrictive definition, natural sciences or engineering, is used throughout this section, although science and engineering are often defined broadly to include social and behavioral sciences.

[11] The absolute numbers have been declining as well. In the fall of 1986, 246,260 students, or 24 percent of first-time, full-time freshmen in the Nation's 4-year colleges and universities, planned to major in natural science or engineering (NSE). In 1978, 285,557 entering students (27 percent of the freshmen in 4-year institutions) expressed a preference for NSE majors. Enrollments are surprisingly stable in the Nation's 4-year colleges and universities, considering demographic trends and recent reductions in government-funded student aid. Unless otherwise indicated, all references to student populations refer to the population of first-time, full-time freshmen entering the Nation's 4-year colleges and universities each fall, as surveyed by the Cooperative Institutional Research Program (CIRP), Higher Education Research Institute, University of California at Los Angeles. Natural sciences and engineering includes premed majors (in 1986, 3.8 percent of all freshmen). See Green, op. cit., footnote 6. The trend data cited below on freshmen preferences are derived from this source.

[12] The lack of comparability in the population of institutions, more than the change from 1986 to 1987, accounts for the differences reported here. Nevertheless, the differences are small.

Figure 2-2.—Freshmen Planned Majors, by Science/Engineering Field, 1977-87



SOURCE: Cooperative Institutional Research Program, The American Freshman (Los Angeles, CA: University of California, Los Angeles, annually).

The decline has not been steady or consistent. Freshman interest in selected science and technical majors such as computer science and engineering rose fairly steadily between 1977 and 1983,[13] as students seeking recession-proof careers gravitated toward high-technology fields. The boom in the semiconductor and computer industries attracted undergraduates while interest in other science fields dropped correspondingly. Freshman interest in engineering in 4-year institutions rose from 10.2 to 11.4 percent between 1978 and 1983, while interest in computer science majors tripled from 1.2 to 4.9 percent during the same period. Beginning in 1984, however, both engineering and computer science declined sharply in popularity, while interest in social sciences began to rise. Most shifts occur between related fields, as students already interested in science in general seek a specialty with healthy job prospects.

Freshman interest in careers, as might be expected, parallels interest in majors. About one-third of NSE majors plan to be engineers, and nearly one-fifth plan medical careers. Interest in a research career dropped from 9.5 percent in 1978 to under 7 percent in 1986, although this varies by field. Physical science majors are twice as likely to be interested in a research career as other NSE majors.

Very few NSE students are interested in teaching: in 1986, just over 1 percent of these freshmen expressed interest in a career in elementary or secondary school teaching, compared to 10 percent of students in other majors. The already low proportion of freshman NSE majors planning teaching careers is only likely to decline further while these students progress through college; in all likelihood many will be recruited away from education and encouraged to pursue academic, research, or other "professional" careers by family, friends, and faculty. Role models are very important in recruiting undergraduates into careers. "Who is to teach mathematics and science?" has become a more urgent refrain than "who is to do research?"

Freshmen at different types of institutions tend to have different major and career preferences (see table 2-2 and table 2-3). Students at private institutions are slightly more likely to be interested in science, and less likely to go into engineering. And interest in science and engineering majors is much stronger among freshmen at more select institutions, particularly for women, as shown in table 2-4.[14] Freshmen at the

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[13] Astin et al., op. cit., footnote 9.

[14] Ibid., pp. 69-71, 85-86. "Select" is defined as mean SAT scores of freshmen.

3

Table 2-2. — Planned Majors and Careers of Freshmen at All Institutions, by Sex, Fall 1987

(in percent)

	Total	Men	Women
Major			
S/E pool	29.3	31.7	22.6
Engineering	9.4	12.0	2.7
Social sciences	8.1	5.6	10.5
Biological sciences	5.5	6.4	4.5
Pre-medicine	2.5	2.5	2.5
Physical sciences	2.2	2.9	1.5
Computer science	1.6	2.3	0.9
Career			
Engineer	8.5	15.2	2.6
Scientific researcher	1.5	1.8	1.2

NOTE: Biological sciences includes agriculture and forestry; physical sciences includes mathematical sciences. Total is first-time, full-time freshmen at all institutions, including 2-year institutions. Total number of students in the unweighted sample was 209,627; percentages reflect weighted national norms.

SOURCE: Alexander Astin et al., *The American Freshman: National Norms for Fall 1987* (Los Angeles, CA: University of California, Los Angeles, Cooperative Institutional Research Program, 1988), pp. 21-22, 37-38, 53-54.

Table 2-3. — Freshmen's Planned Majors and Careers by Type of Institution Attended, Fall 1987

(in percent)

	All institutions (incl. 2-year)	4-Year colleges	All universities
Major			
S/E pool	29.3	27.3	40.2
Engineering	9.4	6.9	13.8
Social sciences	8.1	9.8	10.4
Biological sciences	5.5	4.0	6.6
Pre-medicine	2.5	2.4	4.9
Physical sciences	2.2	2.4	3.1
Computer science	1.6	1.8	1.4
Career			
Engineer	8.5	5.9	12.6
Scientific researcher	1.5	1.4	2.4
Teacher	8.1	10.9	4.2

NOTE: Biological sciences includes agriculture and forestry; physical sciences includes mathematical sciences. The total unweighted number of institutions (including 2-year institutions) in the sample used for calculating national averages was 390, with an unweighted student population of 209,627. This included 53 universities, with an unweighted student population of 91,993; and 278 4-year colleges, with an unweighted student population of 101,221. For sampling and weighting methodology, see source below, pp. 99-105.

SOURCE: Alexander Astin et al., *The American Freshman: National Norms for Fall 1987* (Los Angeles, CA: University of California, Los Angeles, Cooperative Institutional Research Program, 1988), pp. 21-22, 37-38, 53-54.

Table 2-4. — Freshmen Interest in Science and Engineering Majors by Selectivity of University Attended and Sex, Fall 1987

(in percent)

	Men				Women			
	Public univ.		Private univ.		Public univ.		Private univ.	
	Least select	Most select	Least select	Most select	Least select	Most select	Least select	Most select
S/E Major	45.7	50.8	37.5	56.1	28.6	37.5	29.2	47.1
Natural science	16.4	18.8	14.9	17.4	12.8	17.6	11.7	17.6
Social science	4.6	9.7	9.6	14.7	11.3	15.9	14.6	20.0
Engineering	24.7	22.3	13.0	24.0	4.5	4.0	2.9	9.5
S/E Career								
Sci. researcher	2.0	3.4	1.8	4.5	1.5	2.7	1.3	3.7
Engineer	21.9	22.6	11.3	17.9	4.5	4.3	2.6	7.8

NOTE: The 53 universities in the unweighted survey sample included 27 public universities, with an unweighted student population of 64,392; and 26 private universities, with an unweighted student population of 27,601. The percentages reflect weighted national estimates. Selectivity level of low, medium, or high determined by mean total SAT/ACT scores of freshmen. See source below, p. 103, for details.

SOURCE: Alexander Astin et al., *The American Freshman: National Norms for Fall 1987* (Los Angeles, CA: University of California, Los Angeles, Cooperative Institutional Research Program, 1988), pp. 69-71.

most select universities are twice as likely as freshmen at the least select universities to plan careers as scientific researchers.

Trends in Degrees: Field Differences

Baccalaureate awards in science and engineering have tracked overall degree awards, maintaining a fairly steady 30 to 32 percent share for the past few decades. This apparent constancy, however, masks substantial changes in individual fields. Natural sciences and engineering have shown more variation, ranging from about 16 to 21 percent in the past decade, with slight increases in recent years.

Scientists and engineers work in a variety of places and use different skills. Astronomy is dominated by Ph.D.-trained basic researchers in universities, while many B.S.-trained computer scientists and engineers develop products in high-technology companies. While the sciences are broadly similar — in the kind of students they attract, the dynamics of enrollments, degree awards, and job markets — there are significant differences between fields. Analysis of education and employment patterns, and interaction of job markets and student interest, are instructive when disaggregated by field.[15] Since shortages and surpluses occur at the level of the specialty rather than for science and engineering as a whole, looking at this finer level of detail is important.

Science and engineering B.S. awards (following the pattern of all B.S. degrees) rose rapidly in the 1960s, peaked in 1974, and then plateaued with relatively slight increases in recent years (see figure 2-3). Physics degrees have been relatively steady, dropping slightly through the 1970s and increasing again since 1980. In the life sciences, degrees peaked in 1976. The social sciences went through the most rapid increases into the early 1970s, before flattening out for a decade or so. Engineering has followed a different pattern, with slow increases until the 1970s, when degree-taking took off in response to burgeoning job offers and salaries. Most chemists work in industry, and have salaries higher than most other scientists. Bachelor's degree production has been quite steady since the mid-1960s, with slight declines in recent years.

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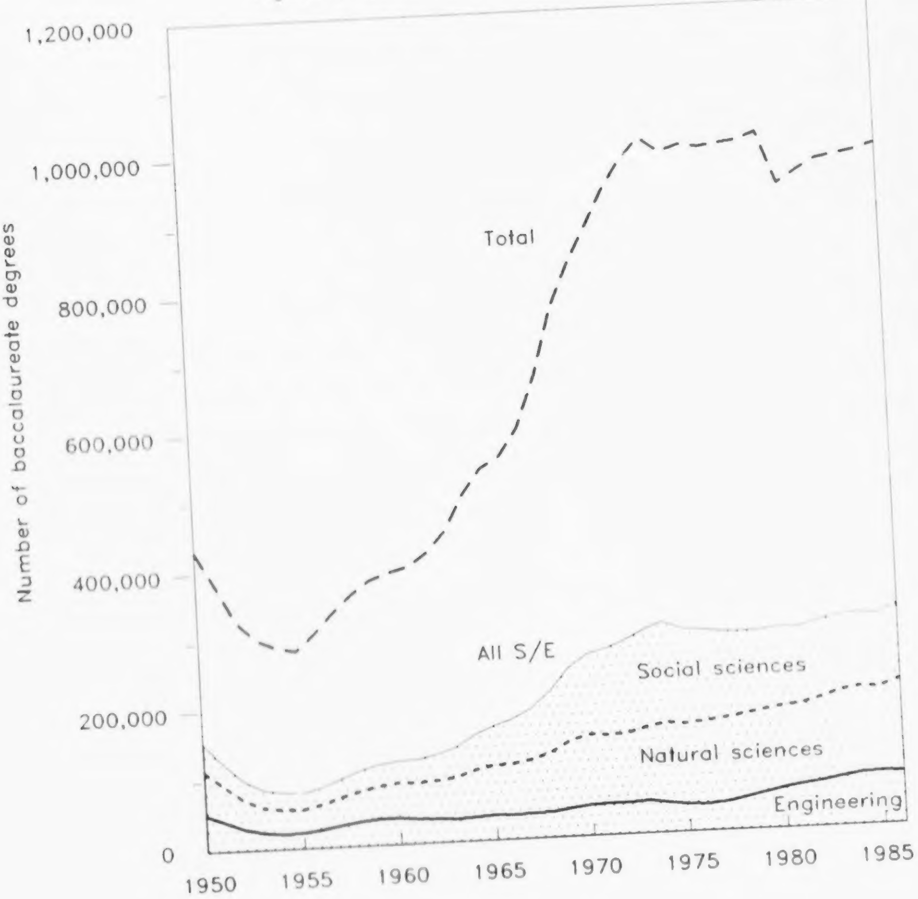
[15] For a recent review that disaggregates data on science and engineering fields, see U.S. Congress, Office of Technology Assessment, "Preparing for Science and Engineering Careers: Field-Level Profiles," Staff Paper, January 1987. The National Science Foundation prepares occasional data profiles on individual fields, for example, National Science Foundation, *Profiles — Mechanical Engineering: Human Resources and Funding*, NSF 87-309 (Washington, DC: 1987).

Figure 2-3.-Baccalaureate Degrees, 1950-86



KEY: S/E = science/engineering.

SOURCE: Betty M. Vetter and Henry Hertzfeld, "Federal Funding of Science and Engineering Education: Effect on Output of Scientists and Engineers, 1945-1985," OTA contractor report, 1987, based on U.S. Department of Education data.

Geological science degrees are closely tied to industrial indicators such as the world market price of oil. This determines the health, i.e., the hiring and R&D posture, of principal employers. In the concentrated and cyclical world of natural resources, there is a surplus of bachelor's- and master's-level earth scientists who started college just before the current downturn in the petroleum and mining industries curtailed exploration and research. As a result, undergraduate enrollments plummeted. B.S. awards, which had doubled between 1974 and 1984, declined over 20 percent from 1985 to 1986, and 25 percent from 1986 to 1987.[16]

It is important to look at mathematical and computer sciences degree data together, since the rapid drop in mathematics degrees during the late 1970s was accompanied by a boom in computer science degrees (in response to burgeoning industry demand for computer specialists). By 1983, bachelor's degrees in mathematics had started rising again. The boom years of computer sciences testify to the ability of students and universities to respond to market demand; the growth rate in baccalaureate awards in the late 1970s and early 1980s was 20 and even 35 percent per year (although many argue this rapid growth stemmed merely from the redesignation of courses, faculty, and students as "computer science" with little change in actual course content, faculty expertise, and student preparation).

In the life sciences, the market for physicians influences biological and medical science undergraduates, since many of them are planning medical rather than scientific careers. In some sense, medicine and research biology compete for students; when the market for graduate students is down, more life science graduates go to medical school. There is a large supply of life scientists, and extended graduate study is necessary to find a job above the level of technician. But degree awards in the life sciences have been declining steadily for the past decade and represent a shrinking proportion of science degrees.

SCIENCE AND ENGINEERING STUDENTS

Although science and engineering students differ from the average college student — they tend to be higher achieving academically and are much more likely to be white and male — changes in the size and composition of the college student population trickle through to science and engineering. Policies that affect higher education in general also affect the science and engineering pool, albeit adjusted for the particular students, universities, and job markets that dominate science and engineering.

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[16] Earth sciences degree data based on surveys conducted by the American Geological Institute, cited in *Manpower Comments*, vol. 23, No. 5, June 1986, p. 18.

Black, Hispanics, and Native Americans

Minorities' college enrollment and retention to degree in science and engineering reflects the generally lagging educational success of minorities (see table 2-5).[17] The continuing social barriers that set minorities apart — language and cultural differences, poverty, political powerlessness, prejudice, and discrimination — are in many cases exacerbated by the traditional white male dominance of the science and engineering professions.[18]

There are relatively few Blacks, Hispanics, and Native Americans in science and engineering. Asians prefer science and engineering to other majors (see figure 2-4). Among high-achieving students, according to Cooperative Institutional Research Program (CIRP), Blacks and Hispanics, as well as Asians, are more interested in NSE than in other majors.

Blacks have made substantial gains in higher education, but their inroads into science and engineering have been modest, and increases have slowed in recent years. Those Blacks who do well academically and take many high school mathematics and science courses are about as likely as their white peers to be interested in science majors.[19] Blacks earn about 3 percent of science and engineering baccalaureates, and 6 percent of all baccalaureates. Only in the social sciences do Blacks earn more than 5 percent of the B.S. degrees conferred. Interest in the social sciences was inspired by early Black leaders in education, sociology, and political change; in the rest of the sciences and engineering, there are few role models and little cultural tradition which promote research careers. And in science and engineering more so than in other majors,

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17. Linda S. Dix (ed.), *Minorities: Their Underrepresentation and Career Differentials in Science and Engineering*, Proceedings of a Workshop, Office of Scientific and Engineering Personnel, National Research Council (Washington, DC: National Academy Press, 1987); and James R. Mingle, *Focus on Minorities: Trends in Higher Education Participation and Success* (Denver, CO: Education Commission of the States and the State Higher Education Executive Officers, July 1987).
18. Lisbeth B. Schorr, *Within Our Reach: Breaking the Cycle of Disadvantage* (New York, NY: Anchor Doubleday Press, 1988).
19. Valerie Lee, "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition," OTA contractor report, 1987.

Table 2-5. — B.S. Degrees in Science and Engineering, by Race/Ethnicity, 1984

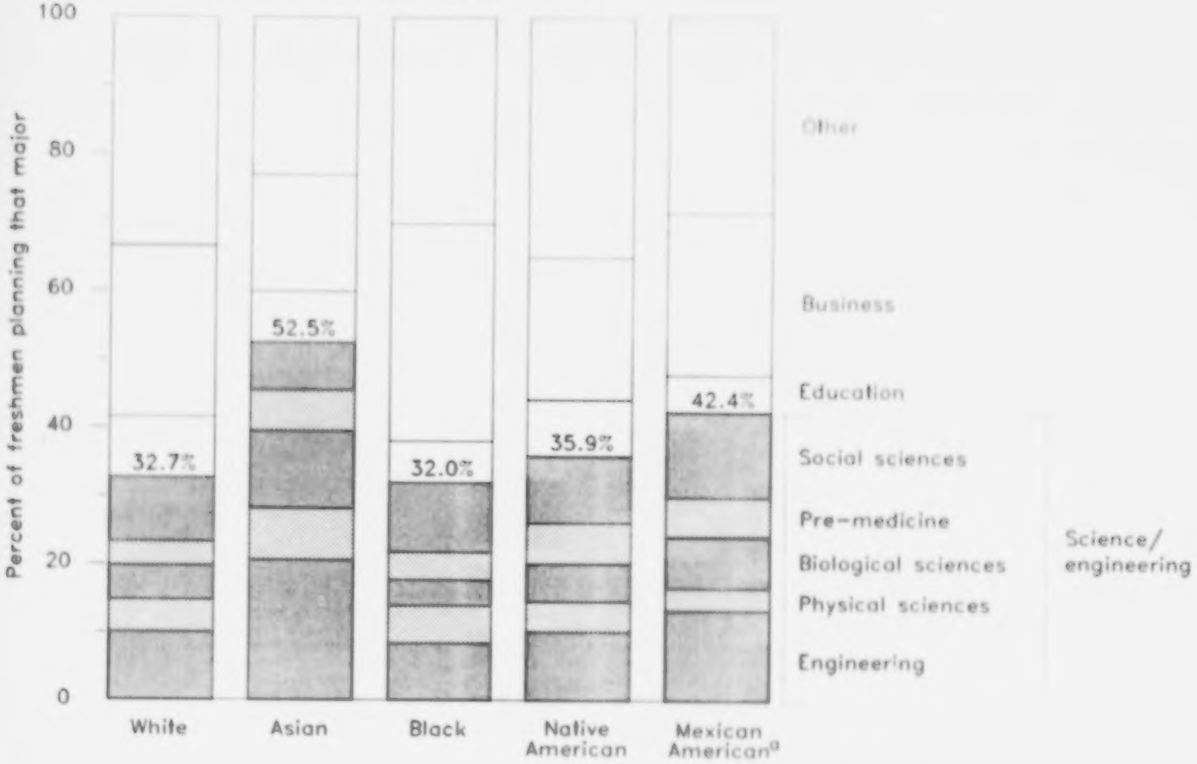
	Total[a]	Percent minority[b]	Black	Hispanic	Native American
All science/ engineering	293,200	7.5	9,400	12,300	400
Physical sciences/ computer sciences/ mathematics	62,700	5.3	1,500	1,700	100
Life/environmental sciences	54,000	6.3	1,300	2,000	100
Social sciences/ psychology	96,600	11.4	5,000	6,000	(c)
Engineering	79,800	5.6	1,700	2,700	100

[a] Includes "other" and no report.
[b] "Percent minority" includes only Black, Hispanic, and Native American.
[c] Too few cases to report.

NOTE: Rounded numbers reported in original source.

SOURCE: National Science Foundation, *Characteristics of Recent Science and Engineering Graduates: 1986*, NSF 87-321 (Washington, DC: 1987), pp. 13-14.

Figure 2-4.-Planned Freshmen Majors, by Field and Race/Ethnicity, Fall 1987



[a]Includes freshmen who categorized themselves as Mexican/American or Chicano; does not includes Puerto Rican-Americans.

NOTE: First-time, full-time freshmen in 4-year institutions only. Physical sciences include mathematics and computer science.

SOURCE: Cooperative Institutional Research Program, The American Freshman (Los Angeles, CA: University of California, Los Angeles, annually).

Blacks are much more likely to drop out than than whites. Blacks are the only group where women have a stronger showing in science, and particularly in engineering, than men.[20]

Hispanics are the Nation's fastest growing minority group in the college-age population. They are only 4.5 percent of undergraduates, and more than one-half of these students attend community colleges. The Hispanic population — two-thirds Mexican-American, 12 percent Puerto Rican, 12 percent Central and South American, and 5 percent Cuban — is concentrated in California, Texas, Florida, and New York.[21] Hispanics' success in education varies with socioeconomic status and values across these subcultures, and fares better in some States than in others. Their educational difficulties are complicated because many of them are recent immigrants with little formal education. High-achieving Hispanic freshman (with an equivalent of "A" or "A-" high school grade point average (GPA)) are less likely to be interested in science and engineering majors, and more likely to be interested in business majors, than all Hispanic freshmen.[22] Hispanic degree-taking in science and engineering fields is low, about 3 percent of baccalaureates. They are more evenly spread among science and engineering fields than Blacks, with a strong showing in the life sciences.

Native Americans may be the most disadvantaged minority group in the United States, as measured by their low socioeconomic status and educational and occupational attainment. They are 0.8 percent of the college-age population, but only 0.2 percent of science and engineering baccalaureates. There is little cause for optimism about increasing their participation in science and engineering.[23]

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[20] Another factor is that the armed services compete for minority high school graduates. The armed forces are attracting a greater share of high school graduates. By 1985, over 90 percent of Blacks who enlisted were high school graduates, a 25 percent increase in enlistment from 1980. Solomon Arbeiter, "Black Enrollments: The Case of the Missing Students," *Change*, vol. 19, No. 3, May/June 1987, p. 17. Also see Holly Hexter and Elaine El-Khawas, *Joining Forces: The Military's Impact on College Enrollments* (Washington, DC: American Council on Education, October 1988).

[21] "Hispanics: Some Basic Facts," *The Chronicle of Higher Education*, Sept. 16, 1987, p. A36. Early in 1987, the newly-founded Hispanic Association of Colleges and Universities qualified 60 U.S. institutions (mostly community colleges) for membership, based on a criterion of at least 25 percent Hispanic enrollment. By the year 2000, 100 institutions are expected to qualify. Cheryl M. Fields, "Demographic Changes Bring Large Hispanic Enrollments to Over 60 Institutions," *The Chronicle of Higher Education*, Oct. 7, 1987, p. A40.

[22] Green, op. cit., footnote 6.

Intentions of minorities may not be as predictive as they are for white students. Even though minorities, especially Blacks, may enter college with high (and often unrealistic) expectations, their usually poorer preparation for technical majors may pave the way for disappointment in ambitious career and degree plans.

The generally poor precollege preparation of most Blacks and Hispanics is particularly telling for science and engineering. On average, Blacks and Hispanics take fewer advanced mathematics and science courses than whites. Educators claim that low minority exposure to science and mathematics in high school and excessive reliance on standardized test scores bars many Blacks from college-level science and engineering. And the paucity of minority role models for minority children is particularly severe in science and mathematics; over one-quarter of students in public high schools are Black or Hispanic, but nearly 90 percent of all teachers and about 93 percent of mathematics and science teachers are white.[24]

What gains minorities have made in science and engineering have derived largely from broad national higher education policies and full-fledged institutional commitment to increasing minority access to higher education. Two broad policy strategies have been applied towards that goal: financial aid (student aid for individuals and institutional aid for historically Black institutions) and special social and academic intervention programs for minority students of all levels. Student aid has been particularly important in helping minorities attend college. Well-organized intervention programs can attract students to science and engineering careers and significantly increase their likelihood of completing an undergraduate degree in science or engineering (see appendix A and box 2-B).

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23. Judith E. Fries, *The American Indian in Higher Education, 1975-76 to 1984-85* (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, March 1987). The term "American Indians" is also used for this group. The small number of Native Americans has precluded formal national analysis.

24. See Office of Technology Assessment, op. cit., footnote 4, ch. 3; data from Iris R. Weiss, *Report of the 1985-86 National Survey of Science and Mathematics Education*, (Research Triangle Park, NC: Research Triangle Institute, November 1987), table 35.

Asians

Recent waves of immigrants to the United States, Asians, have spawned a generation of educational "superachievers" who are especially prominent in science and engineering at the undergraduate level. Predominantly Chinese, Korean, and Indochinese, these children of refugees and of the affluent alike distinguish themselves in mathematics, as reflected by SAT scores, and by other measures, including high school grades and time spent on homework.[25] Dedication, family support, and hard work drive many Asian students toward the elite research universities for their undergraduate education. The 1987 freshman classes at the Massachusetts Institute of Technology (MIT), the California Institute of Technology (Caltech), and the University of California, Berkeley, for example, were over 20 percent Asian. They generally have very high educational aspirations.

Asians are the group most interested in NSE. They also are the only group who consistently enter science and engineering majors while in college. Like any ethnic group, however, Asians are diverse. While many have done well, the newest wave of Asian immigrants include many refugees from different cultures, often with little education and few portable skills, and these children have fared more poorly in U.S. schools.[26]

Women

Among freshmen, the proportion of women planning to pursue NSE majors increased slightly between 1978 and 1986, from 31 to 33.[27] However, women are more likely to drop out of science and engineering majors, and women's degree-taking in science and engineering overall has plateaued. Although more women start out interested in scientific majors and careers, their limited career opportunities may be stifling that interest.

Women planning NSE majors have better high school grades than men. In 1986, 55 percent of these women had "A" to "A-" high school GPAs, compared to 51 percent of the men. However, freshmen men planning NSE majors are more likely to rate themselves as "above average" than are the women planning these majors. Reports from college educators are that women students, particularly those in traditionally male majors such as engineering and the physical sciences, tend to have less self-confidence and drop out of a course or major much more easily than do men, even though they are just as capable, performing just as well, and getting the same grades.[28]

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[25] David Brand, "The New Whiz Kids," *Time*, Aug. 31, 1987, pp. 42-51.

[26] In short, the "superachiever" or "model minority" image is overstated. See Office of Technology Assessment, op. cit., footnote 3, pp. 55-56. Also see *Manpower Comments*, vol. 25, October 1988, pp. 19-20.

[27] Green, op. cit., footnote 6. The proportional increase masks a fall in absolute numbers.

Among NSE majors, females are more interested in research or medical careers than their male counterparts, and less interested in engineering; women tend toward biology, and less towards mathematics-based science and engineering majors (see table 2-6).[29]

Although women have made inroads the last two decades into science and engineering, there are still broad gaps in participation (see box 2-C). Women have higher unemployment rates than men in every field of science, at every degree level, and at all levels of experience. They also earn less in every employment sector. So although women's share of degrees in science has increased markedly in the last 15 years, their opportunities for advancement still lag.[30] Since 1983, the proportion earning degrees in computer science, biological science, and the physical sciences in general have leveled off. A "chilly climate" for women still prevails in many college classrooms. Continued gains for women in science are far from assured.[31]

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[28] William K. LeBold, "Women in Engineering and Science: An Undergraduate Research Perspective," *Women: Their Underrepresentation and Career Differentials in Science and Engineering*, Proceedings of a Workshop, Office of Scientific and Engineering Personnel, National Research Council, Linda Dix (ed.) (Washington, DC: National Academy Press, 1987). Also see Sheila E. Widnall, "AAAS Presidential Lecture: Voices from the Pipeline," *Science* vol. 241, Sept. 30, 1988, pp. 1740-1745.

[29] A related phenomenon is computer phobia among women; even if this fear is overcome, there is evidence that women relate to the machine differently than men. See, for example, Sherry Turkle, "Computational Reticence: Why Women Fear the Intimate Machine," *Science for the People*, September/October 1988, pp. 6-11.

[30] National Research Council, *Climbing the Academic Ladder: An Update on the Status of Doctoral Women Scientists and Engineers* (Washington, DC: National Academy Press, 1983).

[31] Betty M. Vetter, "Women in Science," *The American Woman 1987-88: A Report in Depth*, D. Shavlik and Judith Touchton (eds.) (Washington, DC: Women's Research and Educational Institute, 1987); OTA, op. cit., footnote 3, pp. 50-53; and Barbara D. Webster, "Opening Doors for Women in Academia," *BioScience*, vol. 39, February 1989, pp. 96-98.

Table 2-6. — Planned Majors and Careers of Freshmen at 4-Year Institutions, by Sex, 1978 and 1986
(in percent)

	1978			1986		
	Total	Men	Women	Total	Men	Women
Major						
S/E pool	36.7	45.8	29.8	33.6	41.3	27.1
Engineering	10.2	18.0	2.9	10.1	17.8	3.2
Social sciences	9.2	6.8	11.8	9.4	7.0	11.9
Biological sciences	7.1	8.1	6.1	5.5	5.8	4.9
Pre-medicine	4.5	5.4	5.2	3.8	3.9	3.8
Physical sciences	4.2	5.8	2.6	2.9	4.2	2.1
Computer science	1.5	1.7	1.2	1.9	2.6	1.2
Career						
Engineer	8.9	15.7	2.5	9.0	15.6	3.0
Scientific researcher	2.8	3.4	2.2	1.8	2.2	1.4
Computer programmer	2.8	3.3	2.4	3.0	4.3	1.8

NOTE: Biological sciences includes agriculture and forestry; physical sciences includes mathematical sciences. Total is freshmen at 4-year institutions only. Total number of students in the unweighted sample was 209,627; percentages reflect weighted national norms.

SOURCE: Kenneth C. Green, University of California, Los Angeles, personal communication, 1987.

Academic Quality of Science and Engineering Undergraduates

Apart from sheer numbers, the quality of students going into science and engineering is of prime concern. Quality is difficult to measure, so analysts use proxies such as grades, test scores, and surveys of faculty opinion. By all of these measures, science and engineering have been fortunate in attracting, selecting, and keeping many of the best students.

Entering science and engineering students tend to be higher achieving academically, continue to have greater academic self-confidence, and have higher degree aspirations than nonscience and engineering students. Nearly one-half of 1986 freshmen planning NSE majors reported a high school GPA in the "A" to "A-" range, compared to one-quarter of freshmen planning other majors. NSE majors generally view themselves as very talented, ranking their own academic and intellectual skills far higher than average. NSE students also have had more academic coursework coming into college, in all subjects.

NSE maintains its share of able students, despite fears that more of the best students are choosing business and other majors (see figure 2-5). "A" to "A-" students accounted for a slightly larger proportion of all freshman NSE majors in 1986 (47 percent) than in 1978 (43 percent).[32] In the fall of 1986, almost one-fifth of all freshmen planned to pursue the doctorate, twice the rate among other majors. Nearly one-quarter hoped to complete some type of medical degree. Roughly equal proportions of men and women in NSE planned to obtain a doctorate.[33] As is true with students in other majors, the most academically able NSE students are less interested, as freshmen, in teaching careers.

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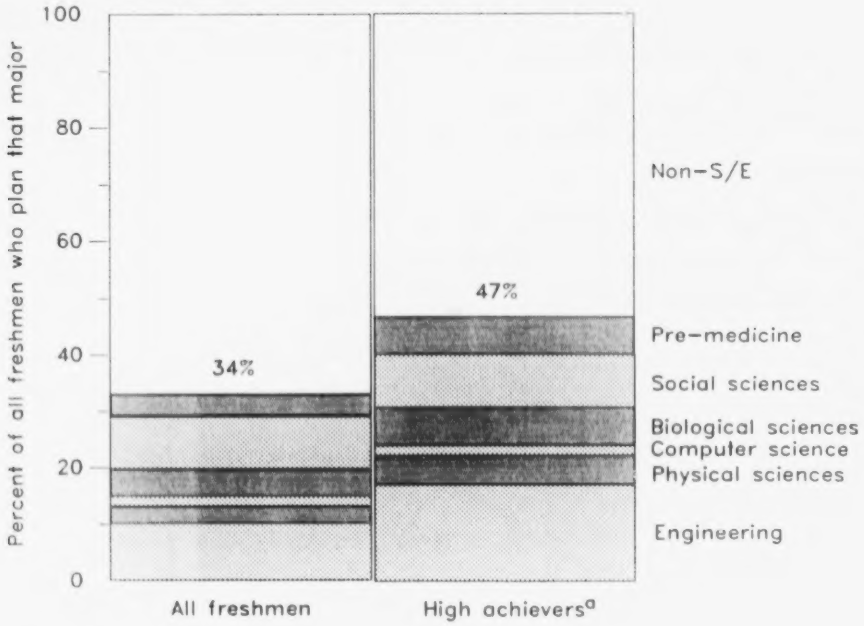
32. Although science and engineering baccalaureates tend to have about the same college grade point averages as other majors (with biological scientists having slightly higher and engineers slightly lower grade point averages), much of any difference may be due to variations in grading practices among courses for different majors. U.S. Department of Education, unpublished Recent College Graduate Survey data.

33. Although the gap in doctoral aspirations between natural science and engineering (NSE) and non-NSE fields declines among the high-talent population, academically-able NSE freshmen in 4-year institutions are still more likely to aspire to the doctorate than their peers (23 percent v. 14 percent). However, medicine is much more attractive to academically-able NSE women (38 percent for women v. 20 percent for men).

Figure 2-5.-Freshmen Choice of College Major, by Achievement, 1986



KEY: S/E = science/engineering.

[a] Freshmen who report their high school grade point average as "A" or "A-".

NOTE: Biological sciences include agriculture and forestry. Physical sciences include mathematics.

SOURCE: Kenneth C. Green, OTA contractor report, 1987, based on data from the Cooperative Institutional Research Program, University of California, Los Angeles.

Retention During College and Career Paths after the Baccalaureate

Some students enter science and engineering during college, but more than twice as many leave (see table 2-7). Some part of this field switching can be attributed to the higher academic ability of students in natural science and engineering. Attrition rates change substantially over time, reflecting changes in market conditions and corresponding student shifts in majors. One study found that NSE lost the most students; only about one-half of freshmen who planned those majors graduated in them (see figure 2-6). In comparison, about 70 percent of business majors stayed the course in business; about 65 percent of social science students stayed in their field. Among scientific majors, engineering retained the most students and physical sciences the fewest.[34]

Although most science and engineering baccalaureate recipients enter the work force upon graduation (see figure 2-7), career paths vary greatly by field. A little under one-quarter of recent natural and social science baccalaureates, and about 10 percent of engineers, have gone on to full-time graduate study.[35] Among employed baccalaureates, most natural scientists and nearly all engineers take jobs in science and engineering, compared to less than one-third of social scientists. Unlike liberal arts majors, 80 to 90 percent of B.S. recipients in mathematics, computer science, and other physical sciences feel that their first job out of college was related to their major.[36]

FEDERAL ROLES IN UNDERGRADUATE SCIENCE EDUCATION

Federal influence on science and engineering undergraduate education is most clear in general Federal higher education policies. The large Federal education aid and access programs, with rare exceptions, are not targeted to particular subjects. Student financial aid and civil rights legislation make college possible for many young people, shaping the size and makeup of the entire college student population, regardless of

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34. Green, op. cit., footnote 6.
35. National Science Foundation, *Characteristics of Recent Science/Engineering Graduates: 1986*, NSF 87-321 (Washington, DC: 1987).
36. Roslyn A. Korb, *Occupational and Educational Consequences of a Baccalaureate Degree* (Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, Center for Education Statistics, March 1987), pp. 1, 7. Estimates are based on the Department of Education's Recent College Graduate Survey of 1983-84, which surveys students about 1 year after their B.S. A liberal arts major may reflect indecision, or a hedging of one's bets, over career directions.

Table 2-7. — College Student Retention, Entry, and Exit From Natural Science and Engineering Majors, by Field, 1981 Freshmen Through 1985 Baccalaureates

	Ratio of defectors to recruits in that major[a]	Percent who stayed with their original major
Biological sciences	1.2	24
Engineering	2.5	61
Computer science	1.6	17
Physical sciences	0.7	35
NSE	1.5	49
Non-NSE	0.8	57

[a] A ratio greater than one indicates that more students "defected" from, or left, that major during college than entered during college.

KEY: NSE = natural science and engineering.

SOURCE: Lewis C. Solmon, "Factors Determining and Limiting the Supply of New Natural Science and Engineering Baccalaureates: Past Experiences and Future Prospects," draft paper presented at the National Science Foundation, July 8, 1986, p. 41, based on data from the Cooperative Institutional Research Program, University of California, Los Angeles. Note that attrition is reported as a percent of total students at a particular time, and therefore does not reflect the overall loss of students from college.

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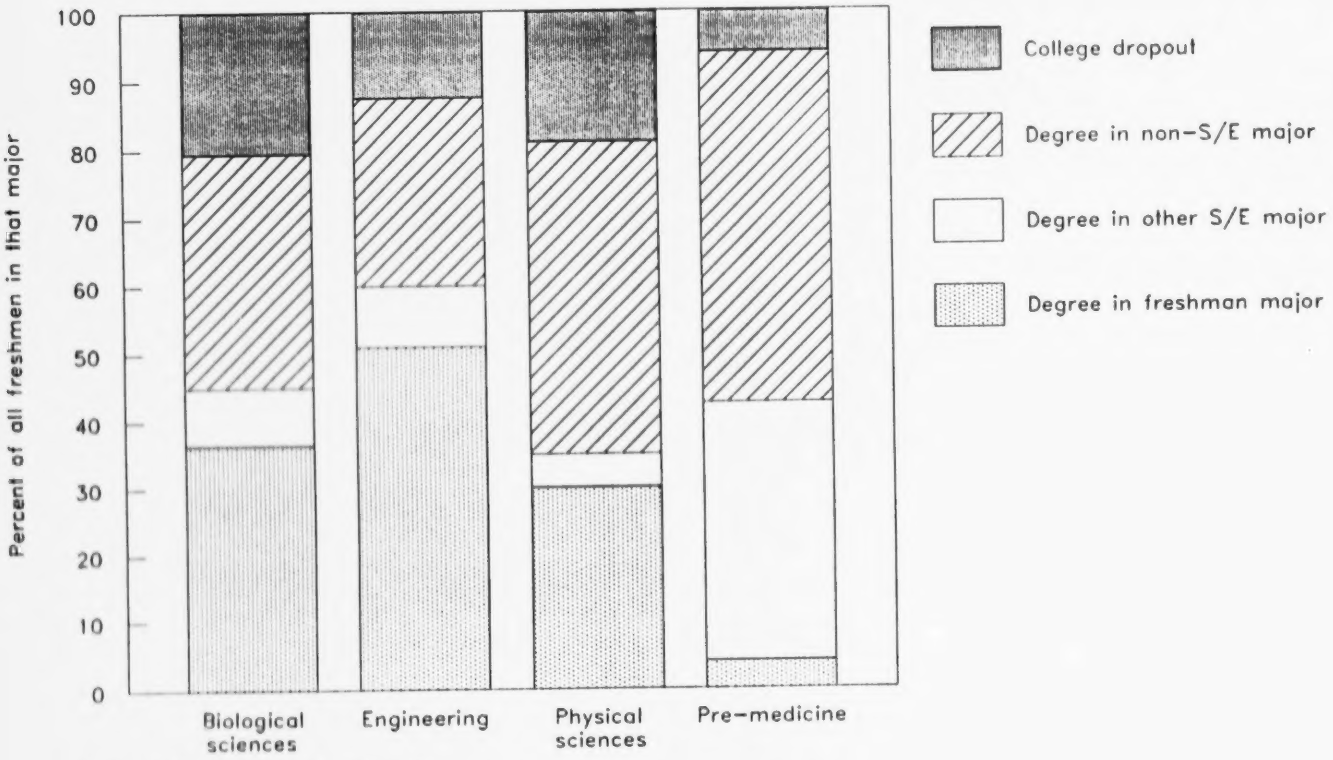
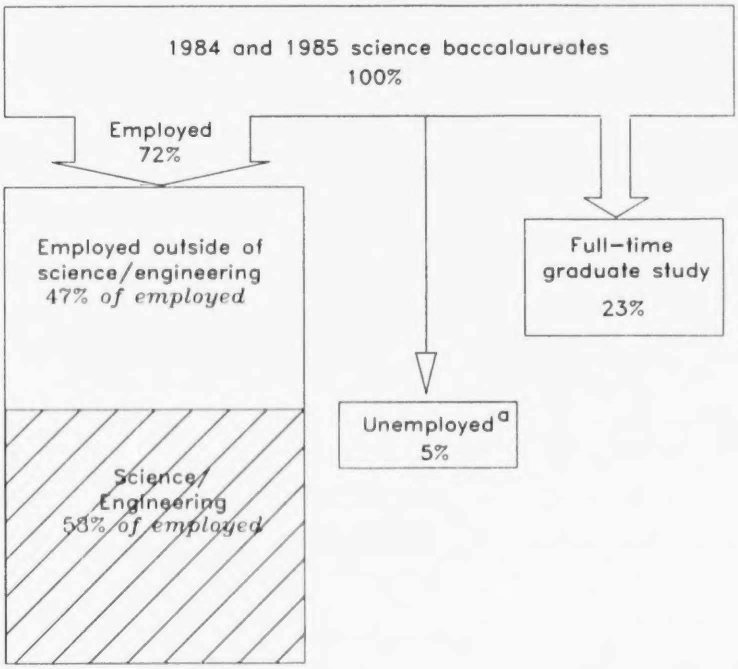
Figure 2-6.–Retention in College, by Freshman Major, 1982 Freshmen in 1986



KEY: S/E = science/engineering.

SOURCE: Kenneth C. Green, OTA contractor report, 1987, based on data from the Cooperative Institutional Research Program, University of California, Los Angeles.

Figure 2-7.-Career Paths of 1984 and 1985 Science Baccalaureates in 1986


1984 and 1985 science baccalaureates
100%
Employed
72%
Employed outside of science/engineering
47% of employed
Science/ Engineering
53% of employed
Unemployed[a]
5%
Full-time graduate study
23%

[a] Includes those not in labor force.

NOTE: Total baccalaureates = 454,000 (100%)
Part-time graduate study = 36,900 (8%)

SOURCE: National Science Foundation, Characteristics of Recent Science and Engineering Graduates: 1986, NSF 87-321 (Washington, DC: 1987), pp. 20-22, 50-51, 54.

major. Institutional aid, particularly for historically Black and land-grant institutions, improves the ability of institutions to deliver a quality education.

Within this context, R&D policies have spawned some much smaller but potent science and engineering education programs to address the special needs of undergraduate science and engineering instruction. Such programs — student research apprenticeships, faculty development, and equipment and facilities support — enrich undergraduate education for a few. These supplementary programs are most often associated with specific R&D goals, and only secondarily affect educational outcomes.

The different goals of education and R&D policies have led to conflicts in developing and administering the respective programs. Higher education policies embody broad social goals of improving educational opportunities, particularly for the underprivileged. Leading-edge R&D has traditionally been a profession of a few high-achieving people and institutions, and Federal science education has targeted this elite.

The Effects of Federal R&D Policies on Undergraduate Education

Federal R&D programs affect undergraduate science and engineering education in four major ways, from indirect to direct:

- Federal R&D spending (defense and civilian) shapes the research agenda and national demand for scientists and engineers, which strongly influences undergraduates' choices of fields and careers;
- academic R&D grants develop infrastructure for science and engineering research and education, including institutions, conferences, facilities, equipment, libraries, faculty, and technicians;
- academic research grants and contracts help support and train a very few undergraduate research assistants (the training component of research grants, mostly targeted to research universities, focuses on graduate students); and
- research agencies fund a few special programs for undergraduate instruction, such as research participation, faculty enrichment, and equipment.

The effects of these research-oriented programs are concentrated at the major research universities. National R&D spending is a major determinant of the supply of baccalaureate scientists and engineers.[37]

Federal influence varies greatly by field. In engineering, where most students can plan on working in industry with a baccalaureate or master's degree, the health of the economy and perceptions of the job market shape students' educational choices. In scientific fields oriented to basic research, the job outlook for undergraduates is more sensitive to Federal programs that dominate university research agendas and Ph.D. training.

While demand for scientists and engineers depends fundamentally on R&D spending, it is also affected by economic, industrial, environmental, regulatory, energy, defense, and other policies that shape the national need for technological goods, services, and workers. The Federal Government also creates incentives, such as tax policies favoring nonprofit educational institutions, tax-free bond issues, and donations to universities and colleges. Such indirect incentives are difficult to quantify, but they clearly invigorate higher education. The government plays a symbolic role, too, in reflecting and reinforcing social attitudes toward education and science.

The National Science Board estimates total national spending for undergraduate science and engineering education is about $20 billion annually, encompassing student and institutional aid as well as special science-related programs. From this pool of money, science and engineering instruction draws about one-half of all spending on undergraduate education.[38]

Trends in the Federal Role

The Federal Government provides about one-third of all revenues of colleges and universities, and nearly two-thirds of aid to undergraduates (including guaranteed loans).[39] Through the early-1960s and early-1970s, Federal support of higher education has been increasing and shifting toward direct support of students. Recently, however, institutional and research-related support has been growing faster than student aid. In 1967, 65 percent of Federal higher education expenditures were for institutional support (largely R&D-related), with the rest allocated to student aid. By 1975, growing student aid accounted for 72 percent, and institutional support only 28 percent. In 1987, student aid has dropped to less than one-half of Federal aid for higher education.[40]

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[37] Lewis C. Solmon, "Factors Determining and Limiting the Supply of New Natural Science and Engineering Baccalaureates: Past Experiences and Future Prospects," presented at a National Science Foundation workshop, July 24, 1986. Solmon found national R&D spending and natural science and engineering salary advantage to be the top two demand factors that correlate with the supply of new baccalaureate natural scientists and engineers.

[38] National Science Board, Task Committee on Undergraduate Science and Engineering Education, *Undergraduate Science, Mathematics and Engineering Education*, NSB 86-100 (Washington, DC: National Science Foundation, March 1986).

Federal policy influence in undergraduate education has been secondary to all-purpose financial support, even where Federal financial support has increased. The Federal role has been stronger in graduate education, where the links are closest to the labor market, and weaker in elementary and secondary education, where primary responsibility remains with the States and localities. States have provided most institutional "mortar and brick" support, which the Federal Government has adorned with smaller, targeted "carrot and stick" programs. In science, however, the Federal Government has had a stronger policy role than in other areas, because of its extensive support of graduate training and university development in science and engineering.

Early Federal science and engineering education policies were linked to other Federal concerns: agriculture and other practical trades (the Morrill Act of 1863 and Hatch Act of 1887); health manpower (the National Cancer Institute Act of 1937 and the Public Health Service Act of 1944); veterans' benefits (the G.I. Bill of 1944); postwar scientific development (the National Science Foundation in 1950); national defense (the National Defense Education Act of 1958); and economic opportunities (the Economic Opportunity Act of 1964).[41] With the increasing Federal involvement in higher education, targeted science and engineering education programs have dwindled in magnitude and political prominence compared to Federal student aid programs.

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[39] National Center for Education Statistics, *Undergraduate Financing of Postsecondary Education: A Report of the 1987 National Postsecondary Aid Study* (Washington, DC: U.S. Department of Education, June 1988), pp. 23-27. The total Federal contribution to higher education revenues includes direct support (about 12 percent of higher education revenues), and indirect support through student aid and federally guaranteed loans (about 13 percent of revenues) and intergovernmental transfers through State and local governments (about 10 percent of revenues). These estimates are based on Lawrence E. Gladieux and Gwendolyn L. Lewis, *The Federal Government and Higher Education: Tradition, Trends, Stakes, and Issues* (New York, NY: College Entrance Examination Board, October 1987), pp. 2-3; U.S. Department of Education, Office of Educational Research and Improvement, *Digest of Education Statistics 1987* (Washington, DC: 1987), p. 229. Also see Gwendolyn L. Lewis and Jamie P. Merisotis, *Trends in Student Aid: 1980 to 1987* (New York, NY: College Entrance Examination Board, 1987).

[40] Gladieux and Lewis, op. cit., footnote 39.

[41] Kenneth Green, "Government Responsibility for Quality and Equality in Higher

Financial Aid for Science and Engineering Students

Student aid is the centerpiece of Federal higher education policy. (States, by keeping tuition low at public institutions, also subsidize access to higher education.) The Department of Education administers various grant and loan programs, of which science and engineering students receive a proportionate share.[42]

Federal financial aid for college students was about $15 billion in the 1986-87 academic year; nearly $6 billion in grants, veterans aid, and work-study funds, and over $9 billion in federally financed and guaranteed loans.[43] Federal aid totals about three-quarters of all student aid. The pattern of Federal aid has changed, with loans increasing in importance (as shown in figure 2-8), and the value of Federal awards relative to college costs has dropped.[44]

Periodically there has been discussion of special Federal scholarships for undergraduates majoring in science and engineering, or in other majors where there is national need.[45] Such aid could be awarded on merit as well as (or in lieu of) financial need. In the past, the need for such scholarships was not perceived as pressing, given the large and then-expanding number of college students, and was seen by some as contrary to the Federal policy of awarding aid based on need. Precedent exists for special Federal aid for undergraduates planning to teach in areas of national need (and merit-based

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Education," *Policy Controversies in Higher Education*, Samuel K. Gove and Thomas M. Stauffer (eds.) (New York, NY: Greenwood Press, 1986), p. 88.

[42] The major research agencies' smaller, targeted undergraduate and graduate programs for science and engineering students are discussed separately, and are not part of the "student aid" package.

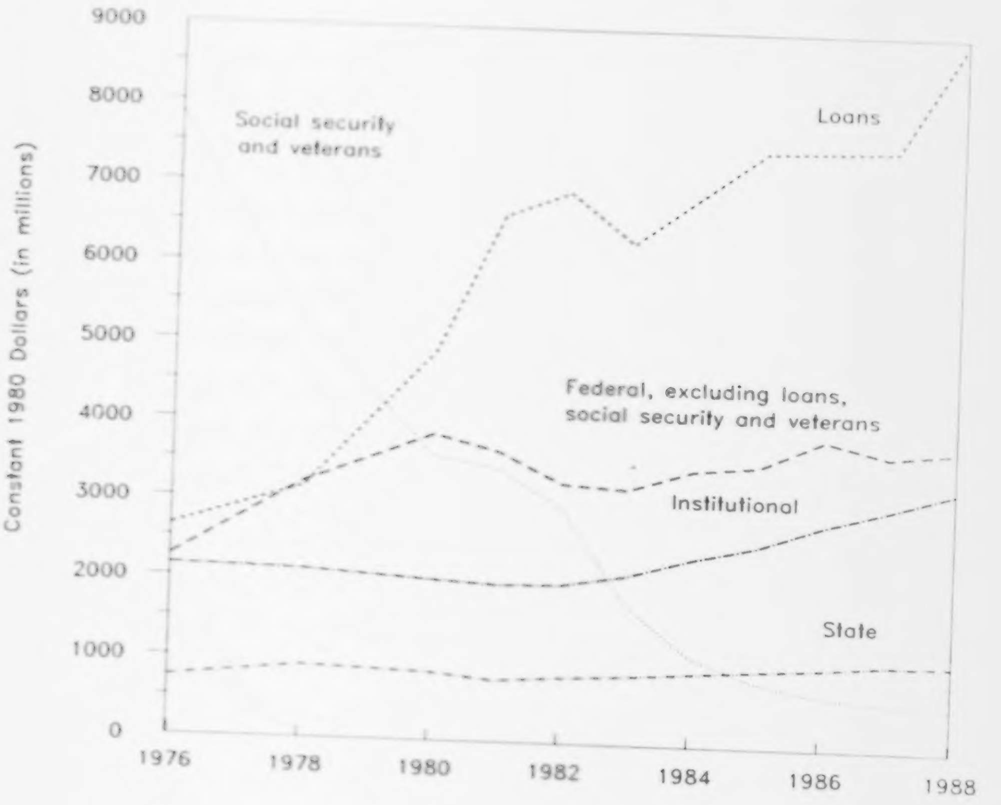
[43] Arthur M. Hauptman and Charles J. Andersen, "Background Paper on American Higher Education: Report to the Commission on National Challenges in Higher Education," prepared for the Commission on National Challenges in Higher Education, Washington, DC, Dec. 16, 1987, p. 12.

[44] For example, James B. Stedman, *Financing Postsecondary Education Attendance: Current Issues Involving Access and Choice*, 88-315 EPW (Washington, DC: Congressional Research Service, Apr. 22, 1988).

[45] Task Force on Women, Minorities, and the Handicapped in Science and Technology, *Changing America: The New Face of Science and Engineering*, Interim Report (Washington, DC: June 16, 1988). During the early years of the National Science Foundation, an undergraduate research scholars program was discussed but never implemented.

5.

Figure 2-8.—Sources of Student Aid, in Constant 1980 Dollars, 1976–86



NOTE: Data for 1977 and 1979 are interpolated.
Data for 1988 are estimated.

SOURCE: Donald A. Gillespie and Nancy Carlson, Trends in Student Aid: 1963 to 1983 (Washington, DC: The Washington Office of the College Board, December 1983), p. 33; and The Washington Office of the College Board, "Update From Washington" (Washington, DC: The Washington Office of the College Board, February 1989), p. 7.

Federal aid has long been awarded at the graduate level for science and engineering students). The interest in subsidizing science and engineering graduates may become more pressing as the college-age population drops.[46]

The Effects of Financial Aid

Research on financial aid[47] indicates that:

- aid increases students' access to college, enrollments, their choice among institutions, and their likelihood of graduating;
- aid helps low-income students much more than it does middle-income or high-income students;
- low-achieving students (most often measured by GPA) are more influenced to pursue undergraduate study by the availability of financial aid than are higher-achieving students; and
- grants (from any source) are slightly more effective than loans and other forms of tuition reduction in increasing access, choice, and persistence. College students are more likely to stay in school when they receive substantial grants or scholarships. Students who receive grants totaling more than one-half of their tuition are less likely to drop out than those who receive no grants or Pell grants at all.[48]

The existence of aid, more than the amount, seems to be the crucial factor in expanding access and enrollments. The amount of aid offered becomes more significant in students' choice among institutions, and in keeping them in college through a degree. Financial aid is becoming more important in students' decision to go to college, and where to go.

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[46] An undergraduate research scholars program could be administered by the Department of Education, the National Science Foundation, or jointly among mission research agencies, and could be leveraged through matching requirements with institutions or private sponsors.

[47] Larry L. Leslie and Paul T. Brinkman, *The Economic Value of Higher Education*, (New York, NY: Macmillan, 1988), ch. 8; Julia A. Heath and Howard P. Tuckman, "The Effects of Tuition Level and Financial Aid on the Demand for the Advanced Terminal Degree," *Economics of Education Review*, vol. 6, No. 3, summer 1987, pp. 227-238. This literature review indicates that other factors affecting college attendance include student ability, cost, family income, and parental education. In one study comparing public and private sources of aid, only public grants were found to be a significant influence on college attendance, especially for lower income groups.

[48] U.S. Department of Education, Office of Educational Research and Improvement data, cited in *Manpower Comments*, June 1987, p. 30; Dennis Martin, "Long-Term Implications of Student Borrowing," in College Scholarship Service, *Proceedings: Colloquium on Student Loan Counseling & Debt Management, Denver, CO, Dec. 2-4, 1985* (New York, NY: College Entrance Examination Board, 1986), p. 59.

Concerns over the rising costs of education, the ability of families to pay (parents and students together pay roughly three-quarters of the total bill for college), and rising dependence on loans relative to grants (loans represent more than half the total financial assistance to college students), affects all students. Minorities show no clearcut differences from whites in how their decisions are affected by financial aid, when socioeconomic status and ability are statistically controlled. (Because minorities are much more likely to be low-income, college aid is particularly important for them.)[49]

Increasing Enrollments

The college population has expanded and diversified with the help of Federal aid, and science and engineering have shared in this expansion. Federal policies that encourage college enrollments or fuel the job market increase the number of college-educated workers, thus expanding the science and engineering talent pool. Programs specifically aimed at science and engineering training (such as the National Defense Education Act) or employment (such as the Apollo program) draw students into science and engineering, although their greatest effect is reallocating talent among some science and engineering fields.

The Federal program that boosted college attendance the most was the G.I. Bill for veterans. It increased the number of Americans with college degrees, and as a result increased the number of those with science and engineering bachelor's degrees. The education deferment of the draft, legislated in 1951, was also a boon for science and engineering, again, by increasing enrollments overall. The Vietnam draft gave a much smaller boost to the male high school graduates entering college during the mid- to late-1960s, with small derivative benefits for science and engineering.[50] (The majority attended 2-year and vocational schools, an option that did not exist for World War II veterans.) The sharp dropoff in Vietnam veterans after 1976 coincides with a slight dropoff in the number of male science and engineering graduates.

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[49] A general discussion of college financing is beyond the scope of this report. See Michael S. McPherson, *How Can We Tell If Federal Student Aid is Working?* (New York, NY: College Entrance Examination Board, May 1988); Hauptman and Andersen, op. cit., footnote 43; Cynthia L. Brown et al., "High School and Beyond: Student Financial Assistance, Student Loans," prepared for MPR Associates, Inc., June 1987; and Roger Thompson, "Student Aid: Year of Uncertainty," *Editorial Research Reports*, vol. 1, No. 19, May 23, 1986, pp. 371-388.

[50] U.S. Department of Commerce, Bureau of the Census, "School Enrollment — Social and Economic Characteristics of Students: October 1976," *Current Population Reports*,

However, attempting to increase the number of scientists and engineers by simply increasing enrollments may be a policy of the past. America has the highest participation rate in higher education in the world; more than 60 percent of high school graduates attend some college. Women attend college at the same rate as men. Minorities (except for Asians) attend at lower rates than Whites, for financial and other reasons, especially their relatively poorer preparation before college. Such factors suggest that further expansion of enrollments may be more difficult than in the past. The bottleneck may now be the preparation children get in the schools rather than college-level assistance; the need for colleges to do more and more remediation is evidence of this new problem.

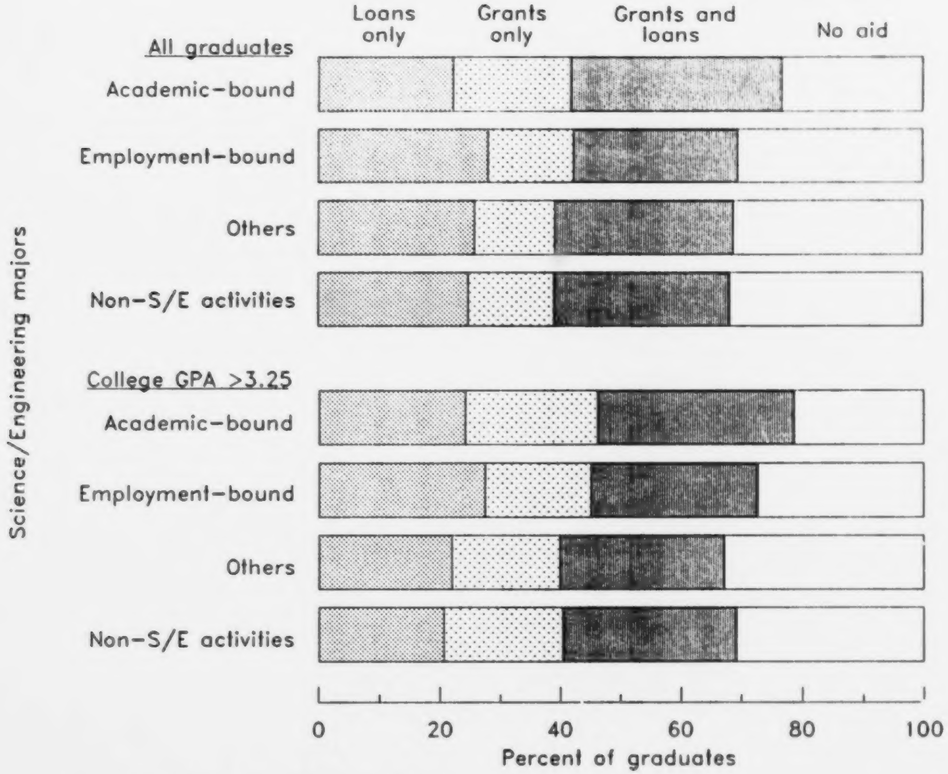
Financial Aid and Field Choice

Does availability or use of financial aid vary by major, and have changing patterns of financial aid affected students choice of major or career plans? There seems to be no strong, direct correlation. Availability of aid, and reliance on that aid, generally is unrelated to undergraduates' choice of major or career.[51] Science and engineering students are more likely to receive grants of all sorts and other campus-based aid (see figure 2-9). In part this is due to their higher than average academic ability, since much of this aid is awarded on the basis of merit. However, even when compared with students of equivalent achievement, science students are still slightly more likely to receive grants.

Series P-20, No. 319, Feb. 1978, p. 4.

[51] Consortium on Financing Higher Education, *Beyond the Baccalaureate: A Study of Seniors' Post-College Plans* (Cambridge, MA: March 1983), p. i; and Applied Systems Institute, Inc., "Financial Assistance, Education Debt and Starting Salaries of Science and Engineering Graduates: Evidence From the 1985 Survey of Recent College Graduates," OTA contractor report, 1987, based on Recent College Graduate Survey data. Financial aid information reported by incoming freshmen in the University of California, Los Angeles' Cooperative Institutional Research Program survey, while not especially reliable, indicates that natural science and engineering (NSE) students are more likely than students in other majors to receive institutional aid. This is probably due to their above-average academic performance in high school (as measured by self-reported grade point average). In general, NSE majors have the same financial aid profile as their peers in other majors.

Figure 2-9.–Type of Aid Used in College by Science/Engineering Baccalaureates, by Immediate Postcollege Career Path and College GPA, 1984



KEY: GPA = grade point average.
S/E = science/engineering.

NOTE: Academic–bound are those S/E baccalaureates who go on to full–time graduate study in S/E.
Employment–bound are those S/E baccalaureates who go on to full–time employment in S/E.
Others are part–time students or part–time employees in S/E.

SOURCE: Applied Systems Institute, Inc., "Financial Assistance, Education Debt and Starting Salaries of Science and Engineering Graduates: Evidence From the 1985 Survey of Recent College Graduates," OTA contractor report, 1987.

There have been recent charges that rising student debt may be steering students inappropriately towards majors leading to more assured jobs and higher-paying careers.[52] For example, since engineers' salaries are higher than average, their ability to repay their debts is also greater; this might encourage some students to major in engineering or make them more willing to undertake debt. However, there is no analytical support for these arguments. Certainly, students' preferences in recent years have shifted towards such majors — business, prelaw, and engineering in particular. But a survey of students who were repaying loans revealed that few of them thought that their loan debt affected their choice of major.[53] And amount of educational debt and loan status are not strongly related to students' areas of study or to their average achievement.[54] Science majors have about the same average loan debt as do other undergraduates. Students of applied science (mostly engineering and computer science) are slightly more likely than humanities students to take out loans and more likely to have higher debt (see figure 2-10).[55]

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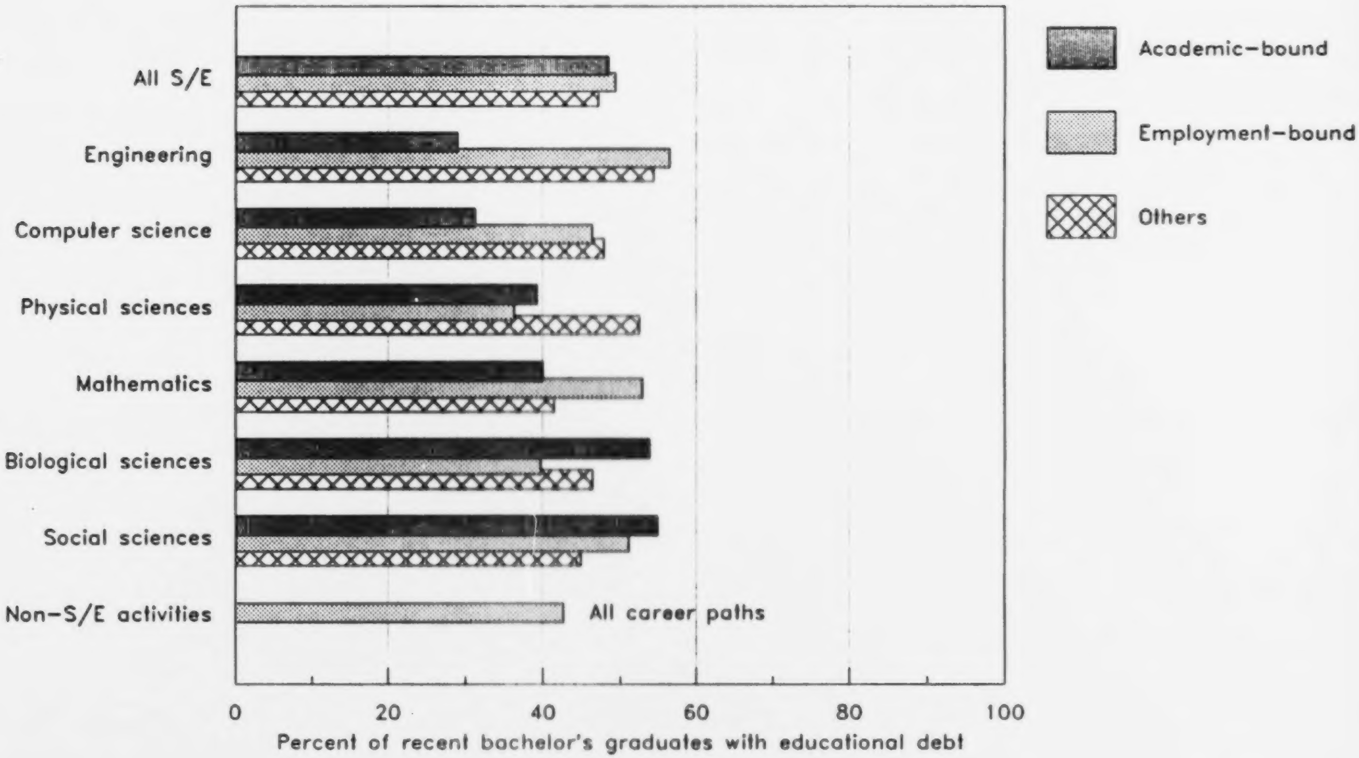
[52] Kathryn Mohrman, "Unintended Consequences of Federal Student Aid Policies," *The Brookings Review*, vol. 5, No. 4, fall 1987, pp. 26-28; American Council on Education, "Student Borrowing Has Implications for Career Choice," *Fact Sheet* (Washington, DC: August 1985); and Carnegie Foundation for the Advancement of Teaching, "The Price of College Shaping Students' Choices," *Change*, May/June 1986, pp. 27-30.

[53] National Association of Student Financial Aid Administrators, *The Characteristics of GSL Borrowers and the Impact of Educational Debt*, survey of 600 students repaying Guaranteed Student Loans in the spring of 1985, reported in Mohrman, op. cit., footnote 52, pp. 27-28; and Martin, op. cit., footnote 48, pp. 45-72.

[54] Edward P. St. John and Jay Noell, "Student Loans and Higher Education Opportunities: Evidence on Access, Persistence, and Choice of Major," prepared for the NASSGP/NCHELP Research Network Conference, Washington University, June 3, 1987, pp. 17-19, based on High School and Beyond Class of 1980 data; Applied Systems Institute, op. cit., footnote 51; and Consortium on Financing Higher Education, op. cit., footnote 51, pp. i, vii. The Department of Education's National Postsecondary Student Aid Study, completed in 1988, includes extensive aid data by field of study, but field-level data have not been analyzed.

[55] Consortium on Financing Higher Education, op. cit., footnote 51, p. 8; and Applied Systems Institute, Inc., op. cit., footnote 51 (based on data from the Department of Education's 1985 Recent College Graduate Survey, or RCG). The RCG results are not controlled for field differences in socioeconomic status, educational costs, etc. A 1984 Carnegie survey of undergraduate students found differences by field in the use of loans: social sciences, 42 percent; biological sciences, 42 percent; physical sciences, 33 percent; and engineering, 26 percent. About 35 percent of 1980 college graduates had some debt at graduation, with a median debt of $2,500. The top quartile had a debt of $3,600 at public institutions, and $5,000 at independent colleges and universities. See National Center for Education Statistics data cited in National Commission on Student Financial Assistance, *Signs of Trouble and Erosion: A Report on Graduate Education in America* (New York, NY: 1983).

Figure 2-10.–Education Debt of Recent Baccalaureates, by Field and Career Path, 1984



KEY: S/E = science/engineering.

NOTE: Academic-bound are those S/E baccalaureates who go on to full-time graduate study in S/E.
Employment-bound are those S/E baccalaureates who go on to full-time employment in S/E.
Others are part-time students or part-time employees in S/E.

SOURCE: Applied Systems Institute, Inc., "Financial Assistance, Education Debt and Starting Salaries of Science and Engineering Graduates: Evidence From the 1985 Survey of Recent College Graduates," OTA contractor report, 1987.

Students do not have to repay loans while they continue in school. Consequently, more widespread and higher debts might encourage students to go to graduate school — a desirable outcome from the point of view of science policy. There seems to be some indication, but no good evidence, that this is happening.[56] Whether high anticipated debt is a factor in students' shift towards higher-paying majors and occupations is impossible to tell. Many factors are involved in changing student preferences, not only college financing.[57]

Apart from student aid, other Federal education and human resources policies increase general access and enrollment (e.g., Title IX of the 1972 Education Amendments) by targeting special populations (women, minorities, the learning disabled, the foreign-born, or the handicapped). Although these policies have broadened the base of women and minorities in higher education, their penetration into undergraduate science and engineering has lagged their entry to the undergraduate population as a whole.

Non-Federal Support of Higher Education

Government appropriations are much more important to public institutions of higher education than to private institutions. State and local appropriations supply about 60 percent of public institutions' revenues, but only about 2 percent of private institutions', which rely much more on tuition and somewhat more on private grants and gifts. Both public and private institutions rely on Federal contracts for 15 to 20 percent of their revenue.

By far the most important actor in science and engineering higher education is the university or college itself. For undergraduates, however, institutional aid accounts for under 20 percent of aid from all sources.[58] Almost all institutional aid is based on financial need. Student aid comes out of the institution's total revenues, and generally is untraceable to its original source.

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[56] Jerry S. Davis, Pennsylvania Higher Education Agency, personal communication, April 1988.

[57] Blacks and Hispanics are more likely than whites to report loans as a major source of funds, but they do not report high levels of debt. The amount of debt is not related to gender, though women have less support of other types and therefore are more likely to borrow. Heath and Tuckman, op. cit., footnote 47, pp. 25, 27-28.

[58] Gladieux and Lewis, op. cit., footnote 39; and Jacob O. Stampen, Student Aid and Public Higher Education (Washington, DC: American Association of State Colleges and Universities, March 1985), p. 82.

States

With State and other support, public institutions have had the fastest growing enrollments, and many have pushed into the top tier of research universities. Their substantial and rapidly growing enrollments have been the bulwark of the enrollment base for undergraduate science and engineering. State-subsidized tuition has made education available to more students, and institutional and other aid has improved the quality of education.

Much State support for higher education is subsumed under general instructional budgets.[59] Direct State support targeting science and engineering education is relatively minor and emphasizes engineering and high technology economic development. Only a handful of need and/or non-need-based programs target science and engineering; non-need-based aid includes tuition equalization, scholarships for meritorious students, and aid for particular fields such as mathematics and science or to particular groups such as veterans, medical students, or police officers (see table 2-8).

Private Support

Voluntary private support, such as grants and gifts from alumni and other individual donors, foundations, and corporations ($8.5 billion in 1987), accounts for about 7 percent of institutional expenditures. Doctorate-granting universities receive about two-thirds of all gifts (mostly private institutions), and private liberal arts colleges about 20 percent; there are no striking differences in who gives to what kind of institution. Gifts from individuals are about one-half of all voluntary support; corporations provide for roughly another one-quarter, and foundations a little less. Voluntary support of higher education has been increasing (in constant dollars).[60] Tax policies have been instrumental in encouraging private contributions and product and property donations to universities and colleges.

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[59] National Commission on Student Financial Assistance, op. cit., footnote 55, p. 67; and Kenneth R. Reeher and Jerry S. Davis, "18th Annual Survey Report, 1986-87 Academic Year," prepared for the National Association of State Scholarship and Grant Programs, January 1987.

[60] Liz McMillen, "28-Percent Surge in Alumni Contributions Lifts Giving to Colleges to $8.5 Billion," *The Chronicle of Higher Education*, Apr. 13, 1988, pp. 1, A34-A36, reporting data from the Council for Aid to Education. National estimates are based on a Council survey of a sample of 1,174 colleges and universities, together accounting for about 85 percent of voluntary support to higher education institutions.

Table 2-8. — State Scholarship Programs, 1986-87

	Undergraduate	Graduate/professional
Need-based		
No. of States:	52	22
No. of programs:	101	37
No. of awards:	1,353,166	26,100
Amt. of awards:	$ 1,399 million	$ 27.4 million
Non-need-based (merit)		
No. of States:	27	16
No. of programs:	76	29
No. of awards:	220,000	5,241
Amt. of awards:	$ 144 million	$ 11.8 million
Total amount:	$ 1,543 million	$ 39.2 million
Other[a]	42 States lots of awards $ 500 million (est.)	unknown 6,200 awards $ 8.9 million[b]

[a] This combines National Association of State Scholarship & Grant Programs (NASSGP) tables 6 and 7, which are partial reportings. In table 6, NASSGP programs listed include loans (Guaranteed Student Loan (GSL), PLUS, loan forgiveness for prospective teachers and health services professionals); teacher fellowships; tuition waivers; work-study; and minority programs. Table 7 lists programs administered by non-NASSGP agencies, such as loans and scholarships to aid veterans, health services students, and tuition waivers to special groups (e.g., minorities).

[b] This figure represents only programs that are exclusively for graduate-level students. Almost all monies are reserved for medical and dental students.

NOTE: Undergraduate, combined undergraduate/graduate, and unknown eligiblity programs are combined under undergraduate for this table. The "other" heading is an underestimate, since there are additional programs listed that are funded by, for example, bond financing of unreported amounts, and there are several large (e.g., GSL loan) programs for which amounts are not reported.

SOURCE: Kenneth R. Reeher and Jerry S. Davis, *National Association of State Scholarship & Grant Programs 18th Annual Survey Report, 1986-87 Academic Year* (Harrisburg, PA: NASSGP, January 1987), pp. 11-33.

Corporations. Corporations provide more than 20 percent of the support received by colleges and universities, in 1985-86 giving about $1.7 billion to higher education.[61] Most is geared toward departmental and research grants, augmented by unrestricted gifts and a relatively small amount of direct support of students (see table 2-9). Corporate giving is concentrated in the largest companies, in manufacturing and R&D-intensive industries such as chemicals, computers, petroleum, transportation, telecommunications, and pharmaceuticals, and insurance companies and banks. Corporate gifts, like research contracts, are concentrated in the top research universities. Corporate giving has been rising steadily, accounting for about 25 percent of all private gifts to education.[62]

Direct corporate support of individual science and engineering students with scholarships is sparse, focused rather on graduate students and on select applied fields such as engineering, computer science, chemistry, and materials science. Indirect support of universities and colleges includes:

- jobs for students (most at the graduate level) working on industry research grants and contracts awarded to individual professors, departments, and joint university-industry research teams;
- employing students for credit or wages in co-op programs (mostly undergraduate engineering students) and industry-based joint research projects (mostly graduate students);
- science and engineering education projects (e.g., precollege teacher training, curricula and software development, equipment trials);
- employee's continuing education and training;
- surplus products donated as gifts, or access to corporate research or computing facilities; and
- that portion of unrestricted industry contributions used by the institution for science and engineering education.

Company-established foundations, which manage and distribute contributions for most large corporations, have been valuable in insulating the flow of charitable

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[61] Council for Aid to Education, *Corporate Support of Education 1986* (New York, NY: February 1988); and ibid., p. A34. National estimates are based on a survey sample of 372 large companies, mostly Fortune 500 companies, which together account for about 37 percent of all corporate charitable contributions.

[62] Paul R. Miller, Jr., Council for Aid to Education, *Business Week* (Special Advertising Section), June 22, 1987, p. 104.

Table 2-9. — Corporate Grants to Higher Education, 1986

Form of corporate support	% of total (in millions)	Amt. of support[a]
Colleges/universities	83	$499.1
Departmental grants	18	110.4
Unrestricted operating grants	12	70.0
Project/research grants	15	88.2
Capital grants	15	87.2[b]
Employee matching gifts	16	98.7
Student financial aid	4	25.6
Grants via consortia	3	19.0
Individuals		
Scholarships/fellowships	6	37.1
Other[c]	10	62.7
Total, 370 companies	99[d]	$599.0
National Total (estimate)		$1,600.0 ($ 1.6 billion)

[a] At this level of detail, Council for Aid to Education reports data only for the companies actually surveyed, and does not make national estimates. These 370 companies together encompass about 40 percent of all corporate giving.

[b] Includes single gift of property valued at $40 million.

[c] Other includes the Council for Aid to Educaton categories of grants to education-related organizations, and "other." Precollege education and economic education (mostly precollege) are not included (together just over $50 million). Unallocated funds are not included.

[d] Does not total 100 percent due to rounding error.

NOTE: The data above include charitable gifts and grants only, and do not include substantial corporate contracts for research and other services. Noncash product and property gifts account for 25 to 30 percent of the total.

SOURCE: Council for Aid to Education, *Corporate Support of Higher Education 1986* (New York, NY: February 1988), p. 5.

contributions from the ups and down of profits and business cycles. Tax-encouraged donations of equipment from computer companies have been invaluable in helping campuses computerize.

Foundations. Foundations gave about $1.5 billion to colleges and universities in 1986-87.[63] Foundation support for science and engineering education is mostly indirect; such support comes from various sources, including other foundations. They typically target their support by field or level of interest, e.g., Andrew W. Mellon in the humanities, Rockefeller in biology, Giles Whiting and Charlotte Newcomb for dissertations.

Foundations contributed about $280 million for natural and social sciences at colleges and universities in 1985-86, and about $150 million for research institutes (see table 2-10 and table 2-11).[64] Graduate and undergraduate student fellowships were $37 million, about 6 percent of total foundation spending in the sciences. Much of the other money went to develop programs and support research. Although foundations play a small funding role, they can have an impact in specialized areas. The Howard Hughes Medical Institute in 1987 launched a large program which includes $30 million in awards to selected undergraduate colleges for programs to attract students, particularly women and minorities, to scientific research careers.[65]

Targeted Federal Undergraduate Science and Engineering Education Programs

The National Science Foundation (NSF) has spearheaded Federal undergraduate science and engineering education activity, as the only agency with this formal responsibility, under its broader mission in science and engineering education. Several mission agencies have small programs, usually linked to their research and laboratories. The Department of Education strongly supports general undergraduate education but plays little direct part in science and engineering education.

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[63] McMillen, op. cit., footnote 60, p. A35.

[64] The Foundation Center, *The Foundation Directory* (New York, NY: 1986).

[65] Liz McMillen, "44 Colleges to Share $30-Million to Improve Education in Biology," *The Chronicle of Higher Education*, May 25, 1988, p. A32. The spending is part of a result of a settlement of a Federal tax dispute. Other Howard Hughes Medical Institute (HHMI) spending will support postdoctoral fellowships, research experience for medical students, and a study of high school science education. A second wave of 5-year HHMI awards, to public and private universities, ranging from $500,000 to $2 million will be made in spring 1989. See *Manpower Comments*, vol. 25, October 1988, p. 26.

Table 2-10. — Foundation Support for Science, by Type of Support, 1985-86

	Social sciences (in millions)	Natural sciences (in millions)
Program development	$167.4	$125.1
Capital support	16.5	92.8
Research	103.5	77.2
Continuing support	90.9	78.9
General/operating support	50.7	17.3
Matching/challenge grant	21.8	19.4
Fellowship/scholarship	25.5	11.4
Endowment	24.4	6.7
Unspecified	13.2	7.0
Total	$332.0	$286.0

SOURCE: The Foundation Center, 1987.

Table 2-11. — Foundation Support for Science, by Recipient, 1985-86

	Social sciences (in millions)	Natural sciences (in millions)
Higher education	$129.8	$151.5
Private coll/univ	63.4	87.7
Public coll/univ	34.0	47.2
Graduate school	32.0	15.3
Community college	0.4	1.3
School	0.7	3.1
Museum/zoo	0.8	38.9
Research institute	106.1	49.0
Professional society	53.9	25.6
Medical facility	1.2	2.4
Library	8.7	14.7
Other‡	66.2	33.8
Total	$332.0	$286.0

‡Direct service agency, church/temple, community fund, governmental unit, library, performing arts group, and not specified.

SOURCE: The Foundation Center, 1987.

Led by NSF, Federal programs have supported institutional capability (equipment, facilities, instrumentation, and technology), student research, college faculty, and to a lesser extent curricula and course materials. NSF undergraduate programs, like their other activities, competitively award limited resources to a select few institutions and students. Most predominantly undergraduate institutions compete for regular NSF research grants and get most of their NSF money this way. However, NSF (and the colleges) have felt the need to create special programs for undergraduates and undergraduate institutions, designed for their needs (which differ from those of the research universities — see below).

NSF and Undergraduate Education

NSF undergraduate programs target 4-year colleges that are unlikely to have strong research infrastructures (research opportunities, equipment, and faculty). Since there are more undergraduate institutions than full-fledged research universities, this has allowed NSF to spread its money widely in making research accessible to undergraduates.

NSF spending on undergraduate science and engineering education generally has paralleled its total education budget, peaking in 1965 and dropping steadily through the early 1980s. Through the 1960s and early 1970s, NSF spent about $30 million per year (over $100 million in 1987 dollars) on undergraduate science education. There is no observed correlation between spending and the number or proportion of undergraduate scientists and engineers produced. However, this is not surprising, as NSF programs have emphasized quality rather than quantity. Some past and current NSF undergraduate programs are listed in table 2-12.

In addition to NSF's undergraduate education programs, a portion of its regular research funds supports undergraduate research assistants. Of particular relevance to undergraduate education are research funds that go to nondoctoral institutions; in 1987, $40 million from regular research programs, $14 million under Research in Undergraduate Institutions, and $1.6 million from Research Opportunity Awards.[66]

The National Science Board in 1985-86 charged a committee with reviewing needs and priorities in undergraduate science and engineering education. The committee

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[66] Richard Quinn and Lola Rogers, National Science Foundation, personal communications, June 1988.

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Table 2-12. — Current and Past National Science Foundation Undergraduate Programs

CURRENT PROGRAMS

(coordinated by the
Undergraduate Science, Engineering, and Mathematics Education Division,
Science and Engineering Education Directorate,
National Science Foundation (NSF))

This list includes NSF programs that provide significant resources to predominantly undergraduate institutions, the undergraduate components of other institutions, and/or undergraduate students. It should be noted that undergraduate institutions and faculty get most of their NSF money by competing for funds under general NSF research and other programs. Regular research support awarded $40 million in 1987 to undergraduate institutions, and $1.5 million for research opportunity awards.

Equipment

College Science Instrumentation Program (CSIP, 1985→)
- (1987 awards were $9.5 million)
- 2-year, matching grants for instructional instrumentation.

Istructional and Laboratory Improvement
- The umbrella under which CSIP is included, this effort also contains a component to support lab equipment for large doctorate-granting institutions to use in their undergraduate programs.

Research

Research in Undergraduate Institutions (RUI, 1982→)
- (1987 was $14.3 million)
- Research and research equipment funds for investigators at predominantly undergraduate institutions. About three-quarters goes to bachelor's and master's level institutions, the rest to Ph.D.-level institutions that offer 10 or less Ph.D.s a year.

Faculty

Undergraduate Faculty Enhancement Program (UFEP, 1988→)
- (1988 budget was $3 million)
- Supports seminars, workshops, etc., to keep current undergraduate faculty current in their field of instruction.

Student research experience

Research Experiences for Undergraduates (REU, 1987→)
- (1987 was $11.9 million)
- Ongoing grant supplements for one or two undergraduate research assistants, and site awards for developing a research program for 5-10 undergraduates.
- Open to all institutions; about 10%, or approximately $2 million, went to undergraduate institutions; the rest went to Ph.D.-granting universities.

Curriculum

Undergraduate Curriculum Development Program (1988→)
- Supports efforts to stimulate significant changes in the content and structure of undergraduate instruction in engineering and calculus. Future plans include extending the program to other disciplines.

Institutional Development

ACCESS - Career Access Program for Women, Minorities, and the Disabled
- Supports comprehensive regional centers to cover undergraduate and precollege educational activities for women and minority students.

Table 2-12 (continued)

PAST PROGRAMS

Equipment

College Research Instrumentation Program (1983-1985)
- Forerunner to the CSIP (see above).

Instructional Scientific Equipment Program (ISEP, 1961-1981)
- Provided matching funds for instruments for instructional laboratories. Open to all institutions.

Faculty

College Teacher Workshops and Seminars (1956-1975)
- Supported summer conferences for undergraduate faculty.

Research Participation for College Teachers (1959-1970, and thereafter)
- Supported summer research for college faculty from small colleges.

Science Faculty Fellowships (1957-1981)
- Provided awards to faculty for sabbatical leave-type activity, for study and for research.

Student research participation

Undergraduate Research Participation Program (URP, 1959-1981)
- Provided full-time summer support plus part-time academic year support for undergraduates to work with faculty on specially designed research projects.
- At its peak in 1966 URP, supported 6,500 students with $6.8 million ($23 million in 1987 dollars).

Curriculum

Science Curriculum Improvement Program (SCIP, 1958-1972, and thereafter)

Local Course Improvement (LOCI)
- Supported development of specific courses by individual faculty.

Institutional development and planning

College Science Improvement Program (COSIP, 1967-1973)
- Provided institutional planning for predominantly undergraduate colleges and consortia; one component for consortia of 2-year colleges and universities, another for minority institutions.

Comprehensive Assistance to Undergraduate Science Education (CAUSE, 1976-1981)
- Institutional planning; open to all institutions.

Resource Centers for Science and Engineering (1978-1981)
- Four large $2.8 million awards aimed at minorities at all educational levels.

Restructuring Undergraduate Learning Environments (RULE)

SOURCE: National Science Foundation, *Undergraduate Science, Mathematics, and Engineering Education*, NSB-86-100 (Washington, DC: National Science Board, March 1986), pp. 10-12; Lola Rogers and Richard Quinn, National Science Foundation, personal communication, May 1988; and Robert Watson, National Science Foundation, personal communication, February 1989.

reviewed NSF's history in this area, and made specific program and budget recommendations for NSF and other actors.[67] The Neal Report was well received by scientists, employers, and universities, and NSF has taken up many of these recommendations (see box 2-C).

Since publication of the Neal Report, NSF has created a Division of Undergraduate Science, Mathematics, and Engineering Education (USEME) in the Science and Engineering Education Directorate, to manage its own and coordinate other undergraduate-level activities across NSF's research directorates. This initiative should increase the attention and money spent on undergraduate education; since the revival of NSF education activities in 1982-83, most of the spending has been on precollege and graduate education, with undergraduate education becoming noticeable only in 1987.[68]

Although programs have come, gone, and changed frequently, undergraduate-level spending since NSF's inception has supported three major activities: undergraduate research; faculty research, seminars, and other professional enhancement; and instrumentation and institutional development at predominantly undergraduate institutions. Smaller amounts have been spent on curriculum development, educational technologies, and educational research.

Student Experiences: Undergraduate Research and Cooperative Education

Undergraduate research experience provides students with invaluable first-hand appreciation of the skills and interests required to be a researcher — socialization that cannot be gained from classroom lectures. Such experience improves education and career preparation, and stimulates interest in science and graduate work.

The schools that are most productive of scientists share an emphasis on individual attention to students and to undergraduate participation in research: Caltech, Harvey Mudd, MIT, and the private liberal arts colleges. Close faculty-student interaction helps to compensate, in many cases, for a lack of extensive research facilities. The "five colleges" (Amherst, Hampshire, Mt. Holyoke, Smith, and the University of Massachusetts-Amherst) use their unique proximity to share and coordinate facilities.

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[67] National Science Board, op. cit., footnote 38.

[68] From 1982 through 1984, very little money was spent on undergraduate education by the National Science Foundation; since 1985, a growing amount has been spent on programs for undergraduate student research, and for faculty, research, curriculum development, and instrumentation.

This provides students (and faculty) at any one college access to a much broader array of faculty, classes, equipment, and research opportunities than would be feasible for any one college operating independently.[69]

The Federal Government also has a role in making undergraduate research possible, directly through NSF and mission agency programs, and indirectly through avenues such as research assistantships on individual investigator grants and research assistant add-ons for minority students. Many undergraduates participate in independent research outside of regular class laboratories (see box 2-D). At MIT and Caltech, nearly every undergraduate does research and/or a senior thesis.

Another variation on the theme of undergraduate research is cooperative education, in which students work for pay and college credit. Although less than 2 percent of undergraduates do formal co-ops, this mechanism is particularly important for students in engineering and business, and to a lesser extent science. Co-op alumni are more likely to receive job offers and earn higher salaries, and say that co-op education gave them a head start on workplace skills.[70] The Federal Government helped expand co-op education with institutional support mandated by Titles IV and VIII of the Higher Education Amendments.[71]

Faculty

At all levels of education, and in all sorts of institutions, students need competent, enthusiastic, accessible teachers. Teachers include faculty and graduate teaching assistants, and even fellow undergraduate tutors.[72] The quality of teaching in large part depends on the institutional environment, whether it encourages and rewards undergraduate teaching via release time for faculty to develop curricula and course materials, tenure review on teaching as well as publications, awards and recognitions for teaching, and matching good teachers to lower level courses.

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[69] "Five Colleges Conference on Cooperation in Undergraduate Science Education," Amherst, MA, Nov. 13-15, 1986.

[70] American Chemical Society, Survey of Chemistry Co-op Alumni, winter 1985.

[71] John Dromgoole et al., *Change Management in Cooperative Education: The Expansion and Development of Title VIII Comprehensive Large Scale Co-op Programs* (Weston, MA: National Commission for Cooperative Education, n.d.). Co-op engineering education is discussed in ch. 4.

[72] James H. Zumberge, "From Specialist to Generalist: The Role of the Graduate School in Strengthening Undergraduate Education," *Vital Speeches of the Day*, vol. 52, No. 10, Mar. 1, 1986, pp. 300-303.

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NSF's special faculty programs have concentrated on predominantly undergraduate institutions. Faculty at undergraduate institutions usually have sparse research resources in the way of equipment or graduate students to assist in research and teaching; at a small department with few colleagues, and with most of their time devoted to teaching, most have little time for research. This is not to say that undergraduate teaching at research universities is not just as vital and in need of attention, but that some parts are easier to "fix" — equipment, faculty experiences, and other tangibles — than others.

NSF's current programs offer stipends for research, conferences, short courses, and summer professional development activities: Research in Undergraduate Institutions; research and equipment support for faculty in predominantly undergraduate institutions; Research Opportunity Awards, which fund undergraduate faculty to work with NSF grant recipients; and the recently instituted Undergraduate Faculty Enhancement, which funds seminars and workshops for undergraduate faculty. Other agencies have small, more informal programs, often as part of the link between laboratories and local colleges and universities. Faculty also benefit from institutional awards.[73]

Institutional Capability

A large part of institutional awards go to equipment, facilities, and libraries. Currently, equipment and facilities refurbishing, renovation, and replacement are considered the top priority not only for institutional health, but for the health of undergraduate and graduate teaching as well. Research and instructional equipment costs are much higher for science and engineering than for other fields. NSF has had several versions of equipment programs; its current effort is the Instrumentation and Laboratory Improvement Program (College Science Instrumentation Program). Such programs are important because it is very difficult for institutions to purchase large, high-cost equipment on regular grants or through indirect cost recovery, which goes mostly to operations and some maintenance.

Many of the formal government science and engineering education programs target minority institutions, particularly historically Black colleges and universities (HBCUs)

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73. In the words of one report: "Student needs, we believe, should be addressed by NSF primarily through support for equipment and faculty needs." American Council on Education, *Towards a National Policy for Undergraduate Science Education: With the Recommendations of the National Higher Education Associations' Task Force* (Washington, DC: n.d.), p. 17. Admittedly, their vested interest is institutional, not students per se.

below). Some programs target the few institutions that have mostly Hispanic enrollments. Most of these programs fund both undergraduate and graduate education, and many are reserved for HBCUs offering graduate degrees. As with many general university programs it is difficult to separate out the effects of such programs on undergraduates.

Minority institutions have needs similar to others, except in many cases the needs are more pressing. The National Science Board identified the most pressing problems as scientific equipment, followed by faculty support, development, and recruitment.[74] These institutions also have special difficulties — high dependence on government funds, relatively poor students who cannot bring in high tuition or alumni donations, and difficulty recruiting the best Black students and faculty in competition with nationally-known universities and employers trying to meet minority recruitment goals.

NSF programs include supplements for research assistants on regularly awarded grants, Research Minority Centers of Excellence, and Research Improvement in Minority Institutions. The National Institutes of Health (NIH) has a sizeable program, supporting research centers and undergraduate (and graduate) students through its Minority Access to Research Careers program. In general, mission agencies target minority institutions, even though they may not have a formal budget to do so (although much of this activity was spurred by a series of Presidential Executive Orders.) Such alliances make a unique contribution to the undergraduate and graduate education of minorities.[75]

The Future of Undergraduate Science Education

The structure of "mainstream" higher education has changed little in the past hundred years: students still congregate on a residential campus, sit in classes taking notes from lecturers and their assistants, and compete on college sports teams. However, there have been major changes in the social setting of higher education, and many have augured significant changes in the structure of universities.

Some particularly substantial changes include mass higher education and the rise of government student aid, working women and changing family structures, the vast expansion of knowledge and the questioning of traditional curricula, and new

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74. The National Science Board, op. cit., footnote 38, pp. 35-36, 50.

75. National Academy of Sciences, "Alliances: An Expanded View," Report and Recommendations, 1987 Symposium, Sept. 23-25, 1987, unpublished manuscript.

technologies, particularly computers. The rise of community colleges and proprietary institutions is a major innovation in education. Such institutions have a growing clientele and demand for the occupational skills of their graduates. Most colleges and universities have yet to act on the recognition that these 2-year institutions are a substantial pool of students for whom they must compete: the labor market is a powerful magnet.

Computer and information technologies have already made an indelible mark on campus. Powerful multipurpose workstations, stand-alone computers, data networks, remote access supercomputers, and computerized recording and analysis equipment pervade classrooms, dormitories, offices, libraries, and laboratories. In the past 10 years, computers have evolved from novelty to a vital part of university life, relied on by faculty, administrators, and students.[76] Employers expect newly-graduated scientists and engineers to be facile in modern computing.

INSTITUTIONAL SETTINGS AND INFLUENCES ON CAREERS

Colleges have a hand in turning students on or off to science. There is evidence that some institutional settings are more effective than others in selecting and preparing high-quality undergraduates for graduate study and careers in science and engineering. Factors found in most institutions that graduate large numbers of future scientists and engineers include: dedicated teaching; a challenging technical curriculum; the availability of professional apprenticeships as researchers, teaching assistants, or co-op students; easy access to high-quality instructional and laboratory facilities; and strong personal and academic support from faculty and other students (see table 2-13). These characteristics can be replicated at other institutions, and effective institutions that provide quality education and encourage students to enter research can be supported and enhanced.[77]

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[76] For example, see Sara B. Kiesler and Lee S. Sproull (eds.), *Computing and Change on Campus* (New York, NY: Cambridge University Press, 1987), esp. ch. 12, on the experiences of Carnegie-Mellon University, which did early and extensive computerization of campus, curricula, administration, and student dorms and activities.

[77] For example, the legacy of the National Science Foundation's Engineering Research Centers and the brand-new Science and Technology Centers may be their socialization of students into the culture of team research. This would be a positive educational effect in the guise of "research" and "innovation."

Table 2-13. — Factors Affecting the Quality of Undergraduate Science and Engineering Education

Factors	Lead actors[a]
Teaching	
• Good faculty	**C/U**, NSF
• Good teaching assistants	**C/U**
• Curriculum and materials	**C/U**, NSF
Professional apprenticeship	
• Research participation (includes conference presentation, etc.)	**C/U, NSF, R&D**
• Job or cooperative work experience	C/U, ED, PRV
• Teaching experience (tutoring, teaching assistantships)	**C/U**
Institutional setting and resources	
• Quality of equipment (including computers)	**C/U, NSF**, R&D
• Access to equipment	**C/U**, NSF, R&D
• Teaching and research facilities	C/U, NSF, PRV
• Libraries, conferences	C/U, NSF
Personal and academic support	
• Intervention programs	C/U, PRV
• Student peers	C/U
• Family	

[a] These organizations have the most direct influence or have had significant programs in the specified area. Colleges and universities clearly shape the kind of undergraduate education they offer, although their programs are often supported by State, foundation, or industry grants; and personnel, facilities, equipment, or other resources.

Key: (The most important actors are in **boldface**.)
C/U - individual college or university
NSF - National Science Foundation
R&D - mission R&D agencies
ED - U.S. Department of Education
PRV - private foundations or industry

SOURCE: Office of Technology Assessment, 1988.

A Diversity of Institutions

Policymaking is complicated by the diversity of American colleges and universities. Diversity is a strength of American higher education, reflecting the breadth of students and their career aspirations. America's 1,500 4-year institutions include small single-sex colleges, large public universities, world-renowned research universities, technical and engineering institutions, liberal arts colleges, and historically Black institutions. These vary in size; curricula; level and field of degrees awarded; emphasis on research, graduate, and undergraduate education; Federal research support; and selectivity of admissions. Over 40 percent of all students are enrolled in 2-year colleges, which are not yet a significant source of scientists and engineers (see box 2-E).

While the top 100 research universities graduate over 70 percent of science and engineering Ph.D.s, those same institutions graduate less than one-half of the U.S. baccalaureates who go on for science and engineering Ph.D.s. There is no single model of the most effective institution for educating future scientists and engineers.

Research Colleges

The terms "research colleges" and "science intensives" have been used to describe a group of private liberal arts colleges that encourage undergraduate and faculty research in the sciences as well as a traditional emphasis on teaching. The environment at these small colleges values teaching, student research, and intimate interaction with a relatively small number of high-quality peers and faculty.

In 1985, a consortium of 50 private liberal arts colleges undertook a self-study that called attention to their special service to the Nation as a feeder of baccalaureate students to graduate programs in science.[78] These colleges issued a second report in 1986.[79] Known as the Oberlin Reports, they presented convincing evidence of these colleges' role as ". . . among the most productive centers of high quality [baccalaureate] education in the sciences."[80] Most of their alumni proceed into graduate study. The

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78. David Davis-Van Atta et al., *Educating America's Scientists: The Role of the Research Colleges* (Oberlin, OH: Oberlin College, May 1985). "Research colleges" has become a recognizable category of institutions, though the term is not embraced even by member institutions. Another 50 colleges probably share the characteristics of those included in the Oberlin Reports. See Office of Technology Assessment, op. cit., footnote 3, pp. 56-58.

79. Sam C. Carrier and David Davis-Van Atta, *Maintaining America's Scientific Productivity: The Necessity of the Liberal Arts Colleges*, Report of the Second National Conference on "The Future of Science at Liberal Arts Colleges" at Oberlin College (Oberlin, OH: Oberlin College, March 1987).

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research colleges, in short, are competitive with the major research universities in preparing undergraduate students for careers in science. But that is only part of the story.

The strength of the research colleges is, first, their selective student body. They sample from one end of the distribution, competing with (mostly private) research universities for "the best and the brightest." Beyond this incoming talent advantage, peers are instrumental in the quality of education and in social support. Also key is the college's small size — typically fewer than 2,500 students, with low faculty-student ratios. Third, they cultivate the attitude that education is an investment, and students pay handsomely for this type of education.

The strengths of the research colleges — small size and limited course offerings — are also weaknesses. They cannot cater to all students. For instance, while strong in the natural sciences, few liberal arts colleges offer a major in engineering (though many offer a "3+2" arrangement with affiliated engineering schools).

The teaching-oriented research colleges receive comparatively little Federal research support, depending more on private gifts and tuition for revenue. Most Federal funding for academic science is awarded as research grants to Ph.D.-granting universities with graduate students and extensive research facilities and staff. No Federal programs target the "research colleges" exclusively; a few small programs, primarily at NSF, focus on predominantly undergraduate institutions. The research colleges fare well in these programs, as do some of the larger comprehensive public universities and some of the smallest doctorate-granting institutions that are allowed to compete in this category. It should be noted, however, that research colleges (and other undergraduate institutions) receive the bulk of their Federal funding through regular competitive grants.[81]

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80. Ibid., p. 26.

[81] Recent expansion of undergraduate programs at the National Science Foundation includes more faculty and institutional support targeted to predominantly undergraduate institutions, as well as support for undergraduate students and education at all kinds of institutions. One policy question is whether increased research funding at the research colleges (as opposed, for example, to honors programs at State universities) would increase the graduate student population in science and engineering. Rolf Piekarz, National Science Foundation, personal communication, December 1988. Also see Thomas E. Hassan and Jane E. Reynolds, "Working Class Students at Selective Colleges: Where Have They Gone?" *College Board Review*, No. 146, winter 1987-88, pp. 4-9, 30-31.

Historically Black Institutions

Minority students tend not to be as well prepared as majority students for undergraduate study. Perhaps more than other students, they need a supportive academic and social environment to succeed in college, of the sort found at many historically Black colleges and universities (HBCUs). Many credit a caring, nonracist social environment, Black faculty role models, and a critical mass of Black students with the educational success of HBCUs.[82] Federal institutional aid also has kept tuition low and aid high.

One-third of all baccalaureates awarded to Blacks are awarded by HBCUs, although they enroll less than 20 percent of Black undergraduates. The HBCUs are particularly productive of natural science students, granting one-half of the mathematics B.S. degrees and 40 percent of the biological sciences and physical sciences B.S. degrees earned by Blacks in the United States (see table 2-14).[83] In 1987, however, only six of the HBCUs offered full engineering curricula. In 1983-84, they awarded 19 percent of engineering baccalaureates earned by Blacks.

Some argue that the best investment in minority talent is where that talent is concentrated — HBCUs. However, fewer Black college students are attending HBCUs.[84] Some universities are attempting to develop a supportive social and academic environment for Blacks within their mostly white campuses (see box 2-F).

The Federal Government extensively supports HBCUs, through general institutional support and research-related programs that target HBCU faculty, students, and departments.[85] Other Federal programs target minority students and faculty in all

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[82] Howard H. Garrison, "Undergraduate Science and Engineering Education for Blacks and Native Americans," in Dix, op. cit., footnote 17, pp. 47-50, 53-54.

[83] Gail E. Thomas, "Black Students in U.S. Graduate and Professional Schools in the 1980s: A National and Institutional Assessment," *Harvard Educational Review*, vol. 57, No. 3, August 1987, pp. 269-270.

[84] Linda Darling-Hammond, *Equality and Excellence: The Educational Status of Black Americans* (New York, NY: College Entrance Examination Board, 1985), p. 14, states that historically Black colleges and universities enrolled more than one-half of all Black college students before 1970, but only 27 percent by 1980. Also see Colleen Cordes, "Colleges Try to Attract Women and Minority Students to the Sciences," *The Chronicle of Higher Education*, Nov. 16, 1988, pp. A33-34.

[85] Executive Order 12320, Sept. 15, 1981, directed agencies (under the supervision of the Department of Education) to work to increase the participation of historically Black colleges and universities in all federally sponsored programs ". . . in order to advance the development of human potential, to strengthen the capacity of historically Black colleges

Table 2-14. — Baccalaureates Awarded to Black Students At HBCU's and All Institutions, by Field, 1980-81

	HBCUs	All institutions	Percent of degrees awarded at HBCUs
Natural sciences	2,145	4,923	44
Engineering	848	2,445	35
Social sciences[a]	3,109	11,423	26
Total S/E	6,012	18,791	32
All B.S.		60,673	34

[a] Includes history, archaeology, and cultural studies.

NOTE: In the South (where all the HBCUs are located), 59% of all bachelor's degrees awarded to Blacks are from HBCUs, as are 61% of science and engineering bachelor's degrees.

Reliable data on degrees granted to minority students at predominantly minority institutions are difficult to secure. That is one reason for the age of the data presented here. This is OTA's best estimate based on data from the U.S. Department of Education. In recent years, more Blacks have been enrolling in non-HBCUs; however, their retention rates are still higher at HBCUs.

KEY: HBCUs = historically Black colleges and universities.
S/E = science/engineering.

SOURCE: OTA calculations, based on Linda Darling-Hammond, *Equality and Excellence: The Educational Status of Black Americans* (New York, NY: College Entrance Examination Board, 1985), p. 18. Also see William T. Trent, "Equity Considerations in Higher Education: Race and Sex Differences in Degree Attainment and Major Field From 1976 Through 1981," *American Journal of Education*, vol. 92, May 1984, pp. 280-305.

institutions (see table 2-15). Institutional support such as Title III of the Higher Education Act, insofar as it reduces tuition, helps bring college within the reach of lower-income students.[86]

State Colleges and Universities

State colleges and universities, more than 550 public 4-year institutions, enroll 4.8 million students and award two-thirds of the Nation's baccalaureates.[87] Most of higher education enrollment growth has been in public institutions, whose enrollments have gone from one-half to more than three-quarters of the national total.[88]

Many State universities were created in the last century as teacher training institutes or "normal" schools. The baby boom multiplied their enrollments and shifted their mission, along with State colleges and universities founded in the 1960s and 1970s, to comprehensive offerings of undergraduate majors, professional programs at the master's level, public service, and research. Some have become full-fledged research universities. These missions today do not always peacefully coexist.

Public institutions are more dependent on State funds, generally less selective, and less expensive to attend than private colleges and universities. They also tend to be larger. Some public institutions, required by State law to admit all resident high school graduates, reduce classes to manageable sizes by "washing out" large proportions of their freshman classes. This attrition wastes talent. Evidence suggests that many students, owing to the sheer size of classes, "fall through the cracks."[89] Large introductory sections of calculus and other gatekeeper courses probably remove science and

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and universities to provide quality education, and to overcome the effects of discriminatory treatment." See 46 *Federal Register* 180 (Sept. 17, 1981) (and Executive Order 12232 of Aug. 8, 1980).

86. James B. Stedman, "Title III of the Higher Education Act: Provisions and Funding," Congressional Research Service, Library of Congress, Mar. 31, 1987; Robin Wilson, "White House Woos Black Colleges, But Critics Question Motives," *The Chronicle of Higher Education*, Sept. 16, 1987, p. A27.

87. Meredith Ludwig et al., *Public, Four-Year Colleges and Universities: A Healthy Enrollment Environment?* (Washington, DC: American Association of State Colleges and Universities, and National Association of State Universities and Land-Grant Colleges, May 1986), p. iii.

88. Robert S. Eckley, "Liberal Arts Colleges: Can They Compete?" *The Brookings Review*, vol. 5, No. 4, fall 1987, p. 32.

89. Alexander W. Astin, *Achieving Educational Excellence: A Critical Assessment of Priorities in Higher Education* (San Francisco, CA: Jossey-Bass, 1985), p. 89.

Table 2-15. — Major Federal Science and Engineering Education Programs for Historically Black Colleges and Universities (HBCUs) and Minority Students

All agencies target HBCUs in their regular programs and have a range of special HBCU programs (research funding and collaborative research, faculty enhancement, student internships, guest lectures, equipment access and donations, institutional development funding) in response to Presidential Executive Orders. At some agencies these programs are gathered under one umbrella program, such as the Environmental Protection Agency's (EPA) Minority Institutions Assistance Program or the Department of Defense's (DoD) Historically Black Colleges (HBC) Council.

This list includes all higher education, both undergraduate and graduate. Major agencies are in **boldface.**

Key to type of program

U - Undergraduate students
G - Graduate students
F - Faculty
I - Institutional

Major Programs Targeting Minority Institutions

National Institutes of Health (NIH)	
• Minority Biomedical Research Support	I
• Research Centers in Minority Institutions	I
DoD	
• HBC Council	I
• Navy DANTES (Defense Activity for Non-Traditional Education Support)	
National Science Foundation (NSF)	
• Research Improvement in Minority Institutions	I
• Minority Research Centers of Excellence	I
U.S. Department of Agriculture	
• 1890 institutions[a]	
U.S. Department of Education (ED)	
• Minority Institutions Science Improvement Program	I
• Howard University	I
• Strengthening Developing Institutions (Title III of the Higher Education Amendments of 1965) (not targeted to science/engineering, but a major program)	I
U.S. Department of Energy (DOE)	
• Minority Institutions Research Travel Program	F
• Nuclear Energy Training Program	U,G,F

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[a] The 1890 institutions are 16 predominantly Black land-grant universities, established under the 1890 Second Morrill Act to provide for land-grant institutions in States where Blacks were denied access to State land-grant institutions established by the first Morrill Act of 1862.

Table 2-15 (continued)

• Laboratory-HBCU joint programs (student internships, joint research, faculty exchange, facility access)	
EPA	
• Minority Institutions Assistance Program includes minority student fellowships	I
National Institute of Standards and Technology (NIST) (formerly the National Bureau of Standards)	
• Graduate Engineering for Minorities	G

Major Federal Programs Targeting Minority Students or Faculty at All Institutions

Minority institutions also win agency support through other competitions. All Federal agencies, particularly DoD, vigorously recruit and hire at HBCUs, both on their own initiative and as part of the Federal Equal Opportunity Recruitment Program. Many regular Federal university, research, and fellowship programs make special efforts and achieve high minority participation, without formal set-asides or targets for minority institutions, students, or faculty.

Health and Human Services/NIH	
• NIH Minority Access to Research Careers	U,G,F
• National Institute of Mental Health Minority Fellowships	G
DoD	
• Office of Naval Research Minority Research Grants	G
NSF	
• Research Careers for Minority Scholars	U
• Engineering Supplements	U
• Minority Graduate Fellowships	G
• Minority Research Initiation	F
• ACCESS — Career Access Opportunities for Women, Minorities, and the Disabled	
National Aeronautics and Space Administration (NASA)	
• Graduate Student Researcher Program, minority focus	G
ED	
• Graduate Professional Opportunities Program (Javits Fellowships)	G
Agency Consortium	
- National Physical Sciences Consortium for Graduate Degrees for Women and Minorities (NPSC) (DOE, NIST, NASA)	G

SOURCE: Office of Technology Assessment, 1988.

engineering students from the pipeline prematurely. While not attrition per se, such experiences dash hopes of a career in science or engineering.

Thus, while the quality of incoming students to State colleges and universities is diluted, these institutions appear to commit two kinds of errors — flunking out students who are capable of earning a baccalaureate degree and discouraging students from pursuing a science or engineering major. These errors are more visible in institutions that admit large freshman classes that include many students only marginally prepared — academically and emotionally — to succeed. Data on attrition, by type of institution and major, would go far to refine or correct such perceptions of "error" in the squandering of human talent.

Research Universities

One hundred or so research universities house the vast majority of academic science and engineering research. The superb resources of research universities — many excellent faculty, graduate students, researchers, facilities, libraries, and equipment — can be a boon to undergraduates if they have access to them, and if the university emphasizes undergraduate teaching along with graduate training. However, in many universities, the commitment to research and graduate education may divert attention from undergraduate education.[90] In a few cases, undergraduates constitute less than one-half of the students. Despite the preeminence of the top research universities in academic science and engineering and their dominance of graduate training, little evaluation has been done of undergraduate education at these elite institutions.

Undergraduate Origins of Science and Engineering Ph.D.s

One way to investigate the effect of undergraduate settings on science and engineering careers is to look at what types of undergraduate institutions produce the most people who go on to get science and engineering Ph.D.s.[91] OTA conducted an analysis of institutions' "productivity" of science and engineering Ph.D.s, and also looked at trends in this institutional productivity over time.[92] Some highlights are presented below; appendix A contains a fuller discussion of this analysis and various lists of the productive institutions.

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[90] "Research Universities Urged to Upgrade Teaching," *The Chronicle of Higher Education*, Nov. 4, 1987, p. A19; and Roger L. Geiger, "Research Universities: Their Role in Undergraduate Education," *Contexts for Learning: The Major Sectors of American Higher Education* (Washington, DC: National Institute for Education, 1985), pp. 74-97.

[91] Previous studies include: National Research Council, *Doctorate Recipients From United States Universities, Summary Report 1984* (Washington, DC: National Academy Press, 1986), pp. 10-24; Todd C. Hanson, *Baccalaureate Origins of Ph.D.s, 1920-1980: A New Study* (Ashland, VA: Randolph-Macon College, 1986); Carol H. Fuller, *An Analysis of Leading Undergraduate Sources of Ph.D.'s, Adjusted for Institutional Size* (Ann Arbor,

As might be expected, the large degree-granting institutions graduate the largest numbers of baccalaureates that go on for science or engineering Ph.D.s. However, their success in undergraduate education fades somewhat when the size of study body is taken into account. Some small institutions send much higher proportions of their bachelor's graduates on for Ph.D.s. than do many of the largest institutions.[93]

MI: Great Lakes College Association, August 1986); M. Elizabeth Tidball, "Baccalaureate Origins of Recent Natural Science Doctorates," *Journal of Higher Education*, vol. 57, No. 6, November/December 1986, pp. 606-620; Davis-Van Atta et al., op. cit., footnote 78; and James N. Spencer and Claude H. Yoder, "Baccalaureate Origins of College and University Chemistry Faculty in the United States," *Journal of Chemical Education*, vol. 61, September 1984, pp. 802-803. An essential element in any such analysis is controlling statistically for differences in incoming student quality or other relevant characteristics. Disentangling attributes that predispose individuals to academic achievement from organizational characteristics that reinforce those predispositions, however, is far easier said than done.

92. Betty Maxfield, "Institutional Productivity: The Undergraduate Origins of Science and Engineering Ph.D.s," OTA contractor report, 1987. Baccalaureate degree data for academic years 1950-51, 1955-56, 1960-61, and 1965-66 (hereafter referred to in tables as 1950, 1955, 1960, and 1965) were extracted from the National Center for Education Statistics annual publications, U.S. Department of Health, Education, and Welfare, National Center for Education Statistics, *Earned Degrees Conferred* (Washington, DC: U.S. Government Printing Office, 1950-51, 1955-56, 1960-61, and 1965-66). (Baccalaureate reference points beyond 1975 would have been unreliable because a high percentage of graduates who pursued doctoral studies would still be in the Ph.D. pipeline.)

Two other data sources were used: the National Research Council's Doctorate Record File (DRF) and the Survey of Doctorate Recipients (SDR) file. The DRF is based on the annual Surveys of Earned Doctorate (SED). The SED is done in cooperation with the graduate departments of Ph.D.-granting institutions for the National Science Foundation. New Ph.D. recipients complete questionnaires that provide information on the new doctorate's demographic characteristics and employment plans. The SDR is a biennial survey of a sample of Ph.D.s in the sciences, engineering, and humanities. The sample has been studied longitudinally, and includes information on doctorates from 1930 to 1986. The SDR was designed to follow the employment patterns of Ph.D.s over time. The active survey sample includes doctorates for the most recent 42-year time span. For example, the first SDR, in 1973, included a sample of doctorates from 1930 to 1972. The 1985 survey, however, includes doctorates from 1942 to 1984. The SDR questionnaire consists of questions on the Ph.D.'s field of employment, type of employment, primary work activity, and salary.

93. The unknown, of course, is the relative quality of the graduates from these different undergraduate environments. Their specialization by discipline, research area, and post-baccalaureate experiences are also of analytical interest.

Adjusting for size significantly changes the list of the most productive institutions. For instance, Harvey Mudd College, a small engineering-intensive liberal arts college in California, ranked 207th when the number of its graduates who went on to earn science and engineering Ph.D.s were compared to other baccalaureate granting institutions, yet its productivity based on the proportion of its graduates who obtained science and engineering Ph.D.s placed it second overall in rank.

Productivity ratios reflect the emphasis that undergraduate institutions put on science and engineering among their bachelor's degrees, as well as the aggregate quality of the undergraduate population. Institutions such as Harvey Mudd or Caltech, which focus on science and engineering, could be expected to send much larger proportions of their baccalaureates on for science and engineering Ph.D.s than could other high-quality institutions with more diverse curricula.

Most of the more productive baccalaureate institutions (adjusted for size) are private. Only three women's colleges and none of the traditionally Black institutions were in the top 100. Fourteen "technical institutions" and 31 private liberal arts research colleges were in the top 100. OTA earmarked several groups of institutions for special analysis: technical institutions, liberal arts colleges, women's colleges, and historically Black colleges and universities.

Productive Institutions

Among the most productive of all institutions (adjusted for size) are technical schools with undergraduate curricula focusing on engineering and the physical sciences.[94] As might be expected from their emphasis on the physical sciences, all but 1 of a group of 15 of these selected for analysis were among the 100 undergraduate institutions most productive of students who earned science and engineering Ph.Ds. Two institutions stood out as particularly productive: Caltech and MIT. During the years selected for analysis, 44 percent of Caltech and 21 percent of MIT baccalaureates went on to earn science and engineering Ph.D.s.

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[94] The institutions were: California Institute of Technology, Carnegie-Mellon, Case Western Reserve, Colorado School of Mines, Illinois Institute of Technology, Lehigh, Massachusetts Institute of Technology, New Mexico Institute of Mining and Technology, Polytechnic Institute of New York, Rensselaer Polytechnic Institute, Rose-Hulman Institute of Technology, South Dakota School of Mines and Technology, Stevens Institute of Technology, Webb Institute of Naval Architecture, and Worcester Polytechnic Institute. See Fuller, op. cit., footnote 91.

Institutions that serve special populations do not provide a large proportion of science and engineering Ph.D.s. For example, only 34 of the 120 women's colleges analyzed had more than 1 percent of baccalaureates obtain doctorates. Three (Radcliffe, Bryn Mawr, and Wellesley) were in the top 100 baccalaureate sources of science and engineering Ph.D.s. For most of these 120 colleges, an average of five graduates per year went on to earn science and engineering Ph.D.s.[95] Similarly, Black colleges and universities, in general, had very few graduates who went on to complete science and engineering Ph.D.s.[96] Two percent of the baccalaureates from the top-ranked Black colleges went on to earn Ph.D.s in these fields.

Trends in Institutional Productivity

Trends in students' propensity to complete sciences and engineering Ph.D.s indicates a link to Federal fellowship and traineeship dollars, and to Federal R&D spending. OTA analyzed trends in institutional productivity of baccalaureates (adjusted for size) for six time points between 1950 and 1975. The proportion of students going on for science and engineering Ph.D.s peaked in 1965. Although the analysis was limited to selected years, this peak generally corresponds to the rise and fall of generous Federal fellowship suppport for graduate students. Appendix B provides data on the productivity ratios of the top 100 undergraduate sources of science and engineering Ph.D.s over time.

During the rapid rise in productivity between 1955 and 1960, nearly 90 percent of institutions increased or remained stable in their productivity ratios. The most noteworthy change occurred from 1965 to 1970, when 89 percent of the top 100 institutions had a decrease in their productivity ratios.

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[95] For comparison, see Tidball, op. cit., footnote 91.

[96] While historically Black colleges enroll 20 percent of Black students, 40 percent of Blacks who pursue graduate study come from the historically Black institutions. See Willie Pearson, Jr., and LaRue C. Pearson, "Baccalaureate Origins of Black American Scientists: A Cohort Analysis," *Journal of Negro Education*, vol. 54, No. 1, 1985, pp. 24-34; and Willie Pearson, Jr., "The Role of Colleges and Universities in Increasing Black Representation in the Scientific Profession," *Toward Black Undergraduae Student Equality in American Higher Education*, M. Nettles and A.R. Theony (eds.) (Greenwich, CT: Greenwood Press, 1988), ch. 6.

The same pattern was exhibited by all types of institutions. However, the 10 most productive and the technical institutions exhibited the strongest rise and fall in productivity; the liberal arts, women's, and Black colleges a more modest peak. While not mirroring the pattern of distribution of Federal funds, the magnitude of differences in productivity among institutional types is not surprising. Most Federal R&D and fellowship dollars go to the elite research universities and doctorate-granting technical institutions.

Baccalaureate Origins of Research Scientists and Engineers

Only some science and engineering Ph.D.s go on to become productive researchers. What factors influence the decisions and preparation of those few who do continue in research careers? To understand the educational path for successful research scientists and engineers, it is important to look not just at Ph.D. production but to identify institutional settings that encourage students who continue beyond the Ph.D. to become active researchers.

The OTA analysis identified the undergraduate origins of Ph.D.s who join the science and engineering work force, looking at science and engineering Ph.D.s working in any science and engineering-related job, and at a more select group engaged in research.[97]

Looking beyond the Ph.D. to employment in science or engineering generates different information about productive educational environments than measures of Ph.D. productivity. Some key differences result from comparing institutions' "researcher productivity" rather than "Ph.D. productivity":

- Ph.D. recipients from highly-productive undergraduate institutions are likely to stay in science and engineering.

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[97] Maxfield, op. cit., footnote 92. Those surveyed in 1985 had received their Ph.D.s from 1 to more than 20 years previously. The analysis was limited to categories of undergraduate institutions (top 100, liberal arts, technical, women's, historically Black) rather than individual institutions. To identify science and engineering Ph.D.s working in research, and trace their educational history, a group of Ph.D.s was identified from the National Research Council's (NCR's) Survey of Doctorate Recipients file. These were then matched with the NRC's Doctorate Records file, which follows a weighted sample of Ph.D. recipients and contains information on work. The two surveys are based on different data sets and are not completely comparable. Methodological information is available in the contractor report.

- About 30 percent of Ph.D.s from these highly-productive undergraduate institutions stayed in basic or applied research.
- Baccalaureate graduates from technical institutions were more likely than graduates from other types of undergraduate institutions to pursue research careers after completing their Ph.D. degrees. Alumni of liberal arts colleges and the top 100 were comparable.
- Ph.D.s from women's and Black undergraduate institutions were much less likely to select research careers.

Tracing the educational paths of successful Ph.D. researchers from highly-productive undergraduate institutions reveals that active researchers come from graduate study at a small number of top research universities. These elite research universites, however, draw on a broader base — the successful graduates of highly-productive undergraduate institutions. The career decisions made by Ph.D. recipients are influenced as much by their college experiences as by their graduate schools.

Box 2-A. — Handicapped Scientists: The Invisible Minority

The physically handicapped — for example, deaf, blind, and those confined to a wheelchair — are an invisible minority in science and engineering. In 1984 they represented a work force of 92,000, or 2.2 percent of U.S. scientists and engineers.[1] In the view of some: "Progress has been made in the cases where the package is 'different,' women and minorities, but much remains to be done . . . when the package is 'faulty'."[2]

The problem of underutilized talent is also a problem of low expectations of teachers and stereotypical views of what a disabled person can and cannot do.[3]

> Individuals without any knowledge of what it means to be disabled make major decisions for us in the light of what they think a handicapped person is capable of doing. It starts in precollege education where some teachers discourage the disabled from attempting a career in science and continues and continues and continues. We, the handicapped, wind up in a box, the dimensions of which are not set by the inherent limitations in the vision and understanding of influential and not-so-influential educators. This squandering of human resources is an injustice second only to the concomitant exclusion of capable and competent individuals from full participation in the academic field of their choice.[4]

Since 1975, colleges and universities that receive Federal funding must make science and other courses available to handicapped undergraduates. Under the National Science Foundation's program on Research Experiences for Undergraduates, various campuses around the United States provide disabled students with summer introductions to research, encouraging them to pursue careers in science.

Programs such as that hosted by the Science Institute for the Disabled at East Carolina University, in Greenville, NC, have succeeded in improving educational opportunities, access to laboratories, and employment in science and technology for

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1. This estimate is from a National Science Foundation survey, cited by John J. Gavin, Engineering and Economics Research, Inc., testimony, Subcommittee on Science, Research, and Technology, Committee on Science, Space, and Technology, U.S. House of Representatives, *Women, Minorities, and the Disabled in Science and Technology* (Washington, DC: U.S. Government Printing Office, June 28, 1988), p. 131.
2. Ibid., p. 132.
3. Virginia Stern, Project on Science, Technology and Disability, Office of Opportunities in Science, American Association for the Advancement of Science, testimony, in Subcommittee on Science, Research, and Technology, op. cit., footnote 1, pp. 92-93.
4. Gavin, op. cit., footnote 1, p. 133. Later in his testimony he observes the irony that: "Many universities appear to exploit the physical abilities of athletes who may be somewhat slow academically, but not the mental capabilities of those who may be physically limited."

handicapped students. The emphasis has been on raising the awareness of teachers and counselors and linking handicapped students and educators through various networks.[5]

Out-of-school "informal" education programs based in science centers and museums augment campus-based programs of formal instruction sensitive to the needs of the handicapped. For example, the Disabled Access program of the Exploratorium in San Francisco, begun in 1986, has been expanded through partnership with the San Francisco Volunteer Center's Youth Quest Internship Program. Youth Quest is an experimental education and community service project for middle school adolescents. An internship program trains volunteers on how to make 600 Exploratorium exhibits accessible to visitors with mobility, hearing, and vision impairments. Disabled mentors and students speak with the interns, heightening their awareness that disabilities do not diminish curiosity.[6]

Programs that bring handicapped students (of all ages) together in educational settings with scientists (disabled and others) are needed to erase stereotypes and present opportunities that create and sustain interest in research careers. Such programs bring new meaning to the familiar words "recruitment" and "retention."

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[5] Michael Heylin, "Hands-On Research for Disabled Students," *Chemical & Engineering News*, Aug. 15, 1988, p. 25.

[6] Ellen Lieber, "Youth Quest Interns Assess Exploratorium Exhibits for Accessibility," *ASTC Newsletter*, November/December 1988, pp. 9-10.

Box 2-B. — Retaining Hispanics and Blacks in Engineering: California's Minority Engineering Program

The California Minority Engineering Program (MEP) has dramatically improved the retention of Black and Hispanic students in engineering majors in California public universities and colleges.[1] Not only are MEP students much more likely to stay with engineering than are minorities students not in MEP, but they even outperform majority engineering students (see table below). MEP began at one institution in 1973. In 1982, the State funded the expansion of MEP to most other California university campuses. In 1986-87, about 2,500 students were in MEP.

Crucial elements of MEP — and crucial to most intervention programs — are:

- peer support, tutoring, and community building among minority students;
- academic support through science and mathematics workshops; and
- professional and personal support through participation in student organizations, summer jobs, internships, and career awareness activities.

The founder of MEP, Raymond B. Landis, emphasizes the particular importance of helping students through the freshman year, usually the most difficult phase of academic and social adjustment for minorities. His relatively low-cost programs includes in-depth, formal university and academic orientation, clustering MEP students in the same classes so they can work together on the same assignments, upper-class mentors, and a 24-hour student study center. Regular classes are supplemented with both prefreshmen bridge programs and workshops. MEP also facilitates employment and career development through summer jobs, internships, and career presentations.

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[1] California Postsecondary Education Commission, "Retention of Students in Engineering: A Report to the Legislature in Response to Senate Concurrent Resolution 16 (1985)," unpublished draft, December 15, 1986; Raymond B. Landis, "The Case for Minority Engineering Programs," *Engineering Education*, vol. 78, No. 8, May 1988, pp. 756-761; and Cheryl M. Fields, "What Works: California's Minority Engineering Program," *The Chronicle of Higher Education*, Sept. 30, 1987, p. A33. See also National Action Council for Minorities in Engineering, *Improving the Retention and Graduation of Minorities in Engineering* (New York, NY: 1985).

In 1984-85, 19 California public institutions enrolled over 31,000 engineering undergraduates and awarded 5,391 engineering baccalaureates, about 7 percent of national enrollments and degree awards.

Three-Year Retention Rates of Fall 1982 Engineering Freshmen, Students in and Not in the Minority Engineering Program (MEP)

(as percent of entering freshmen)

	All Students	Blacks in MEP	Blacks not in MEP	Hispanics in MEP	Hispanics not in MEP
University of California	47	64	23	57	21
California State University	67	79	30	88	41

Box 2-C. — Douglass Project for Rutgers Women in Mathematics and Science

The Douglass Project at Rutgers University's Douglass College was launched in September of 1986 to increase the number of female students in mathematics and science. The project is open to all women on the New Brunswick campus.[1]

The project sponsors peer study groups, career planning workshops, and a mentor program that includes seminars with presentations by role models in academia and industry. Target audiences are high school students, teachers, and parents. Grants are also sought for an on-campus summer institute. Douglass coordinators consider this outreach component to be the most crucial of the project because of the 9th and 10th grade science and mathematics "gatekeeper" function. Director Ellen Mappan is working with Arlene Chasek at Futures Unlimited, a support program targeting female high school students interested in science and mathematics, in developing the precollege program.

Although the Douglass Project is relatively new, the response has been enthusiastic. Over 100 students participated in the first-semester activities and suggested ideas for future Douglass Project components. Thematic study groups are especially popular. The interest generated by the project literature has even resulted in the establishment of a residence house for undergraduates. The Douglass Project is funded by a 3-year, $123,500 grant from the New Jersey Department of Higher Education's Fund for the Improvement of Higher Education. Contributions have also come from the Associate Alumnae of Douglass, the Ellis and Adrienne Anderson Science Enrichment Fund, the Provost's Excellence Fund, and the Joe and Emily Lowe Foundation.

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[1] Doris Kulman, "DC Project Encouraging Women in Math, Science," *Rutgers Newsletter*, Dec. 5, 1986.

Box 2-D. — The Neal Report

In 1986 the National Science Board concluded an in-depth study of undergraduate science and engineering education.[1] The report of the Task Committee identified three areas of undergraduate science and engineering education needing particular attention:

- equipping laboratories and making laboratory instruction and research an important and vibrant part of undergraduate education;
- upgrading the qualifications of faculty; and
- improving courses, curricula, and the quality of instruction.

The committee called upon all major actors — universities and colleges, States, corporations and foundations, and mission agencies — to do their part in each of these three areas. The special roles and needs of 2-year and minority institutions, and the importance of institutional diversity, were also noted. The committee recommended that the National Science Foundation (NSF) spend an additional $100 million each year on laboratory instruction, faculty enhancement, curriculum development (particularly in mathematics and engineering), research participation, instructional equipment, and minority institutions.[2] These funds and programs could be highly leveraged through matching as well as by "setting examples" for universities, States, and industry. Noting that Federal agencies and corporations focused their attention and spending on research and research-linked graduate education, the committee recommended that NSF, mission agencies, and other research sponsors find new ways to involve undergraduates and undergraduate faculty in research.

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[1] National Science Board, Task Committee on Undergraduate Science and Engineering Education, *Undergraduate Science, Mathematics and Engineering Education*, NSB 86-100 (Washington, DC: National Science Foundation, March 1986), known as the Neal Report after the chair of the Task Committee.

[2] Since the publication of the report, continuing deterioration of conditions has increased cost estimates. National Science Foundation Director Bloch secured a promise to double the budget of his Agency by 1992. While congressional appropriations in fiscal years 1988 and 1989 were disappointing, in the context of a $2.2 to $3.0 billion budget, the Task Committee's price tag attached to their recommendations seems modest.

Box 2-E. — Undergraduate Research Participation: U.S. Department of Energy Student Research Program

The Department of Energy (DOE), as part of its mission to develop scientists and engineers in fields relevant to DOE's mission, supports undergraduate student research. The Student Research Participation program (SRP) each year provides about 1,200 talented college juniors and seniors the opportunity to do summer research at DOE laboratories. This mentored research provides students a unique opportunity for hands-on experience as part of a research team at sophisticated facilities.

The SRP program is effective; its alumni go on to higher degrees, do research, and excel in science, engineering, and medicine. Students gain not only a professional understanding of research and career paths, but self-confidence as well.[1] Some representative comments reflect the enthusiasm of SRP students for the experience, and the lasting impact it had on their careers:

> "My participation in research efforts in immunology at Argonne was pivotal in my choice of career and contributed greatly to subsequent research efforts."

> "My appointment resulted in my attending grad school rather than becoming a medical technologist — which was my original career plan."

> "To date, I still feel that my summer with Brookhaven was the most exciting, and perhaps, most important event in my professional career."

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[1] Frank M. Vivio and Wayne Stevenson, *U.S. Department of Energy Student Research Participation Program: Profile and Survey of 1979-1982 Participants* (Washington, DC: U.S. Department of Energy, January 1988). In 1987 the Department of Energy (DOE) evaluated the Student Research Participation program, looking particularly at the long-term impact on students' choice of fields and decision to go on for a graduate degree and work in research. The evaluation also investigated to what extent students' choice of degrees and research areas supported DOE's mission research. The evaluation surveyed a sample of students who had been in the program between 1979 and 1982, thus allowing 5 or more years for long-term effects to be seen, and for transitory effects to disappear. As with all such "people development" programs, it is difficult to tell how much of the success of alumni is due to their high ability and interest coming into the program, and how much is due to the additional boost the program may give them. What is clear, however, is that the whole program, from selection of students to the research experience itself, generates a cadre of research-oriented, high-caliber scientists and engineers.

Women's decisions about the attractiveness of graduate school and their degree aspirations were much more affected by SRP than were those of men. However, the SRP group still reflects national patterns: women are much less likely than their male counterparts to plan a Ph.D., and less likely to work in the physical sciences or engineering or at a university. The SRP program also has a high proportion of minority participants, particularly Blacks.

Box 2-F. — Community Colleges: An Alternate Entry Route?

The 1,300 U.S. community colleges enroll over one-half of first-time freshman — 2 million in 1985. They fill several niches in science and engineering education. First, they provide an alternate educational route into the science and engineering pipeline for some students, by preparing them for transfer to B.S.-granting colleges.[1] Second, and most important to the overall research and development effort, they train technicians and technologists. Third, a growing part of community college services is customized retraining, primarily for industry technicians. Many community colleges have a regular contract training agreement with local companies; over one-quarter of students receive employer-subsidized job-related training.[2] In some cases State funding is prorated to provide more money for students in vocational courses, in the interest of economic development and work force training. Another, smaller role of community colleges is providing high school students with courses unavailable in their schools.

One estimate is that 5 to 15 percent of all community college students transfer to 4-year institutions.[3] About 40 percent of community college graduates transfer.[4] Transfer of students into engineering from community colleges almost compensates for attrition of freshmen and sophomores at baccalaureate-granting institutions. It is unclear, however, whether students who transfer in as sophomores or juniors from community colleges are more likely to complete a B.S. than are students who entered as freshmen.

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1. G.R. Kissler, "The Decline of the Transfer Function," *Improving Articulation and Transfer Relationships*, F.C. Kintzer (ed.) (San Francisco, CA: Jossey-Bass, 1982); Western Interstate Commission for Higher Education, *Improving the Articulation/Transfer Process Between Two- and Four-Year Institutions* (Boulder, CO: 1985); and Arthur M. Cohen and Florence B. Brawer, *The Collegiate Function of Community Colleges* (San Francisco, CA: Jossey-Bass, 1987).
2. Cheryl M. Fields, "Many Aggressive Community Colleges Focusing on Training Workers for Fast-Growing Fields," *The Chronicle of Higher Education*, Feb. 25, 1987, p. 21.
3. Richard C. Richardson, Jr. and Louis W. Bender, *Students in Urban Setting: Achieving the Baccalaureate Degree*, Association for the Study of Higher Education, cited in "Vocational Focus of 2-Year Colleges in Urban Areas Helps to Perpetuate Social Inequality, Report Says," *The Chronicle of Higher Education*, Apr. 2, 1986, p. 15. (If the 30 percent rule — of all B.S. degrees earned, 30 percent are in science and engineering — holds for transfers in, a 10 percent transfer rate means that about 60,000 (20 percent) of baccalaureate scientists and engineers each year hail from community college origins. This estimate seems high, or optimistic, depending on one's perspective.
4. Daviel D. Savage, "Community Colleges Open Door to Education," *New York Times*, Feb. 2, 1987, letter.

This transfer opportunity is particularly important for minorities, since those Blacks and Hispanics who continue their education beyond high school are much more likely than whites to enter community colleges. The disproportionately large number of minority students who begin their collegiate careers at community colleges makes the transfer function socially imperative.[5] However, in a national perspective community colleges are not "helping" the educationally disadvantaged towards 4-year degrees. Blacks and Hispanics are much less likely to transfer out of community colleges than are whites.

A key policy question is how to help make community colleges a fertile educational environment for minorities. States with large minority populations, such as California and Florida, have established student assessment and placement programs in cooperation with 4-year institutions to prepare those who wish to transfer in pursuit of the baccalaureate.[6]

Community colleges provide an alternate, "late entry" route to the main education pipeline. Given the high percentage of minority students in community colleges and the dearth of minorities in science and engineering, this alternate route to a science or engineering degree, and therefore teaching as well as research, must be explored.[7]

States and Congress in recent years have paid increasing attention to the role of community colleges in high-technology training. Congress directed the National Science Foundation (NSF) to expand eligibility for several college assistance programs to community colleges. Legislation has proposed that NSF support and guide technician training.[8] However, programs to encourage the use of community colleges as a stepping-stone to higher degrees are much rarer.

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[5] J.G. Avila et al., *Petition to Increase Minority Transfer From Community Colleges to State Four-Year Schools* (San Francisco, CA: Mexican American Legal Defense and Educational Fund, Inc.; and Public Advocates, Inc., 1983).

[6] See, for example, Cheryl Fields, "Community Colleges Discover They Are at the Right Place at the Right Time," *Governing*, February 1988, pp. 30-35.

[7] For example, see Martin Haberman, "Alliances Between 4-Year Institutions and 2-Year Colleges Can Help Recruit More Minority Students into Teaching," *The Chronicle of Higher Education*, July 27, 1988, p. A28.

[8] H.R. 2134, introduced in April 1987 by Rep. Doug Walgren, requires the director of the National Science Foundation to carry out an advanced technician training program, making matching grants to community and technical colleges to provide training in strategic fields. The bill was referred to the House Committee on Education and Labor.

The success of transfer programs is difficult to assess, in large part because of lack of information. Data that trace the educational paths taken by community college students would be useful to determine whether funding mechanisms might be put into place to reward community colleges for transferring students to 4-year institutions.[9]

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[9] Jim Palmer, "Bolstering the Community College Transfer Function: An ERIC Review," *Community College Review*, vol. 14, No. 3, winter 1986/1987, pp. 58-60.

Box 2-G. — Why Blacks Persist to the Baccalaureate at the University of South Carolina

The University of South Carolina has the largest percentage (14 percent) of Black students of any major, predominantly white campus in the United States.[1] The University has not only successfully recruited, but more importantly, has retained and graduated Black students.[2] Although entering Blacks had lower SAT scores and predicted grade point average, the retention and graduation rates for Black students entering in 1976-78 actually exceeded the rates for white students. This contrasts starkly with the national average, where Blacks are twice as likely to drop out. While there is no surefire recipe for success in higher education, the reasons for this uncommon occurrence at this one university are instructive:

- student involvement, including holding leadership positions in campus organizations;
- Black faculty serving as advisors to organizations in which Black students participate;
- housing arrangements that put Blacks together on campus; and
- a "critical mass" of Black students, 2,500 in this case, ensuring the opportunity for a good social life.

A poll of Black students yielded the following reasons, in order of their importance, for the University's high Black student retention rates:

1. individual perservance;
2. family pressure and support;
3. helpful Black students;
4. helpful Black faculty and staff; and
5. special programs and the superior quality of Black student academic preparation.

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[1] A.W. Astin, *Minorities in American Higher Education* (San Francisco, CA: Jossey-Bass, 1982).

[2] Michael F. Welch et al., University of South Carolina, "Factors Contributing to Black Student Retention at the University of South Carolina," report of research completed under a grant from the South Carolina Commission on Higher Education, August 1987. Three Black women for every two Black men enroll at the University. Total undergraduate enrollment is 18,000.

A study concluded that Blacks enjoy a campus climate of acceptance that is relatively free of racial discrimination, especially in the classroom. They also participate in a special freshman orientation course to help them adjust to campus life.[3]

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[3] Ibid., p. 39. This course has led to the establishment of the National Center for the Study of the Freshman Year Experience on Campus. Elizabeth Greene, "South Carolina's Gardner: Self-Appointed Spokesman for the 'Largest Educational Minority' — Freshmen," *The Chronicle of Higher Education*, Oct. 7, 1987, pp. A41-43. For an evaluation of the course, see Mark G. Shanley, University of South Carolina, "An Exploratory Longitudinal Study of Retention, Persistence, and Graduate Rates of Freshman Seminar Course Participants and Non-Participants at the University of South Carolina During the Period 1979-1986," doctoral dissertation, 1987.

Chapter 3

Graduate Education and the University

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Chapter 3

Graduate Education and the University

The United States has a globally respected tradition of graduate student as research apprentice, intimately linking research and education. The graduate student earns an advanced degree by acquiring specialized knowledge, research skills, and experience working in the laboratory with a faculty mentor.

The centerpiece of basic research training in the United States is the research university, the public and private institutions that grant most science and engineering Ph.D.s and receive the lion's share of Federal and non-Federal academic research and development (R&D) funds.[1] The top 100 research universities represent less than 3 percent of all U.S. institutions of higher education but about one-third of all science and engineering Ph.D.-granting universities. Collectively, they receive 82 percent of Federal academic science and engineering obligations and house nearly two-thirds of full-time science and engineering graduate students.[2]

The resources and capabilities concentrated in these universities have been the mainstay of basic research and graduate education in the United States. Interest in the health of the national research work force and the universities themselves gives the Federal Government a twofold interest in graduate education at universities. David Hamburg cautions about considering the universities too narrowly as a "manpower machine" for producing scientists and engineers for specific needs: "I would urge taking a broader view of the 'state of health' of the national science and technology enterprise of which academic R&D is a unique and vital part."[3]

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[1] "Science and engineering" includes the social sciences as well as the physical and biological sciences, mathematical and computer sciences, and engineering.

[2] The top 100 research universities are defined here in terms of amount of Federal R&D funds received. This group correlates well with "high-quality" universities as determined by surveys of scientists and academics. See National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions, Fiscal Year: 1986*, NSF 87-318 (Washington, DC: 1987); U.S. Congress, General Accounting Office, *University Funding: Patterns of Distribution of Federal Research Funds to Universities*, RCED-87-67BR (Washington, DC: February 1987).

[3] David A. Hamburg, Carnegie Foundation, testimony before the U.S. Congress, House Committee on Science and Technology, Task Force on Science Policy, July 9, 1985, p. 13.

WHAT IS GRADUATE STUDY?

College gives students a basic education in fundamental science and engineering knowledge. Becoming an independent research worker demands the advanced specialized learning and hands-on apprenticeship of graduate study. Upon completion of the baccalaureate degree, the educational system offers science and engineering students two further degree goals: the master's and the doctorate. Both degrees are awarded following a term of apprenticeship in graduate school, but there is a considerable difference between them. The short course is the master's degree, usually 1 or 2 years of study, mostly in the classroom. The specialized knowledge of the master's recipient brings enhanced earning power and professional responsibility. The long course is the Ph.D., 4 to 6 (if not more) years of low-paid apprenticeship, which gives the survivor full professional standing.

The Master's Degree

The master's degree serves many purposes — professional credential, way station to the Ph.D., and consolation prize for leaving doctorate study.[4] The master's has long been an important final degree for many professions, including engineering and the applied sciences, but is a less significant credential for the research work force. Master's programs are usually focused more on practical knowledge than on research or academic enrichment. Over three times as many people receive science and engineering master's degrees each year as Ph.D.s (see figure 3-1). The master's is most valued in the applied sciences; engineering accounts for one-third of science and engineering master's recipients.

Most engineering schools have two tracks for their graduate degree programs. One track is for those wishing to do research; it is typically comprised of a 1-year master's of science program, which leads into a Ph.D. program. The other track is the master's of engineering (M.E.), usually a 2-year program that may lead into a doctorate of engineering program. Both of the programs in this track are applications-oriented.[5]

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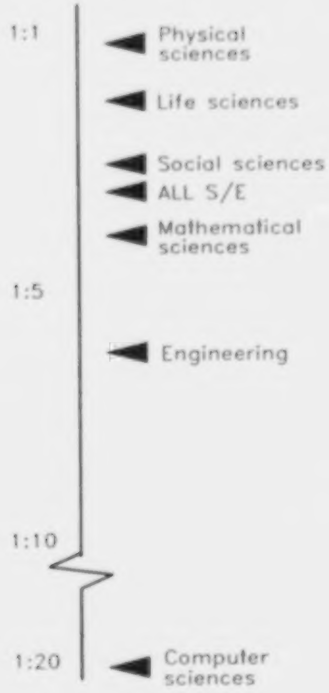
[4] Judith S. Glazer, *The Master's Degree: Tradition, Diversity, Innovation*, ASHE-ERIC Higher Education Report No. 6 (Washington, DC: Association for the Study of Higher Education, 1986), p. xiii. Here the word "master's" encompasses all first professional degrees.

[5] Engineering disciplines, even within the same institution, differ in the value they accord the M.E. degree. At the University of California, Berkeley, for example, one-quarter of its civil engineering master's level students earn the M.E.; in mechanical

Figure 3-1.-Ph.D.-Master's Degree Ratio, by Field, 1986



Key: S/E = science/engineering.

SOURCE: Office of Technology Assessment, 1988, from National Science Foundation data.

11

The proportion of entering graduate students planning to complete the master's degree only is difficult to estimate, but it lies somewhere between 35 and 85 percent.[6] About 30 percent of graduate students are in departments that grant only master's. A few of these continue for Ph.D.s elsewhere. But many additional master's-planning students are in doctorate-granting departments, and many Ph.D. students will drop out with only a master's, so a higher proportion of all graduate students, perhaps as high as 65 percent, actually end up with a master's.

The attractiveness of a master's degree in science or engineering varies with the demand and supply of those with higher credentials. In fields with generous supplies of Ph.D.s, as in most life sciences, the holder of a master's degree may work as a laboratory technician. (There are differences, however, by employment sector as well as field: in industry, the M.S. scientist is frequently a fully independent researcher.) A robust job market is likely to lure students away from school with only a master's degree and to discourage students from continuing to the doctorate.

The doctorate, however, is a sine qua non for an academic faculty or research post, and increasingly important for professional research positions in industry. This chapter focuses on students pursuing the doctorate.

Doctoral Study

Doctoral programs in science and engineering are not only the final formal stage of education, but also initiation into the research community. Doctoral study in the sciences or engineering usually takes 4 or more years (assuming the student does not already have a relevant master's degree). The first year or two is often spent in advanced classes, and preparing for oral and written qualifying examinations that most universities require new graduate students to pass before they can continue their studies. The beginning graduate student often also teaches undergraduates as a teaching assistant, or may do research. Some entering students have already arranged to work

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engineering, this proportion is only 10 percent; and the Department of Electrical Engineering awards barely 1 or 2 a year (Pamela Atkinson, University of California, Berkeley, personal communication, November 1988).

[6] Information is not regularly collected on "Ph.D. candidates." Rather, the National Science Foundation collects data on all graduate students by part-time and full-time status, and by whether they are in doctorate-granting or master's-granting institutions. About 60 percent of science and engineering graduate students are attending full time in institutions that grant Ph.D.s. Few research Ph.D.s come from outside this core population.

with a certain faculty member, and may have a research agenda planned out. Most new graduate students, however, spend no more than a year learning about various research activities at their university.

The choice of a research project and thesis advisor depends on a constellation of factors: what positions are available in various laboratories, the student's interest, funding opportunities, a mentor's perceptions of what constitutes a significant research problem (i.e., potential thesis topic), and luck (timing and serendipity). Most doctoral students are doing research nearly full-time after a few years. The graduate student is not only a scientist in training, but a productive researcher as well. The uncertainty of basic research means that research projects change during the course of thesis research. To earn a Ph.D., the graduate student must make a significant contribution to knowledge in his or her field, complete a written thesis, and pass an oral examination.

The U.S. model is not the only model. Appendix C discusses approaches by other nations to graduate study. Those few who embark on doctoral study in the United States are highly selected. The average quality of science and engineering graduate students is higher than that of baccalaureates, and no evidence suggests any substantial decline.[7]

THE MARKETS FOR PH.D.S

Graduate students respond to two different science and engineering labor markets: a "pregraduate" market for university teaching and research assistants, and a dominant "postgraduate" market for academic and other research scientists and engineers. Federal policies and programs affect both of these markets.[8]

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[7] This conclusion is based both on qualitative assessments and test scores. Office of Technology Assessment data, 1987; National Commission on Student Financial Assistance, *Signs of Trouble and Erosion: A Report on Graduate Education in America* (Washington, DC: 1983), pp. 73-74; and Thomas Hilton, *Trends in the GRE Scores Reported to the NSF and to Selected Graduate Schools: 1974-1980* (Princeton, NJ: Educational Testing Service, January 1982). Several recent studies are reviewed in Arthur M. Hauptman, *Students in Graduate and Professional Education: What We Know and Need to Know* (Washington, DC: Association of American Universities, 1986), pp. 40-44.

[8] This section on pregraduate and postgraduate markets is paraphrased from Robert G. Snyder, "The Effectiveness of Federal Graduate Education Policy and Programs in Promoting an Adequate Supply of Scientific Personnel," OTA contractor report, June 1985, p. 4. A third, nonscience and engineering market would be that for baccalaureates who seek MBA or law degrees.

Graduate education has a long history of "work-study" in the form of research and teaching assistantships. This serves the dual purposes of providing training in research and teaching and at the same time assisting faculty in their research and teaching responsibilities. The demand for graduate student enrollments increases as undergraduate enrollments rise or academic R&D support increases. By funding academic research, the Federal Government affects demand for research assistants. Policies that change college enrollments also change the demand for undergraduate (and graduate) teaching, and thus the demand for graduate teaching assistants.

The postgraduate market for doctorates in some respects resembles the traditional market for other occupations — as the economy and research enterprise expand, increased job openings and higher salaries attract more students and produce more graduates. Two key dissimilarities, however, exist — the time lag created by protracted educational preparation and the strongly academic market.

The time lag needed to attain a doctorate is considerably longer than for most occupations. Not only is a college degree needed, but 4 to 8 years of doctoral study. (And in some fields, the professional career is not launched with receipt of the doctorate, but after 2 to 3 years of postdoctoral study.) Hence, the market response is very long, which brings with it significant, and sometimes disruptive, oscillations between shortages and surpluses.

A second distinctive feature of the market for doctorates is its dependence on employment in academia itself. Academia is a nontraditional market in its use of tenure and its emphasis on externally-funded research, both of which provide stability and insulation from some, though certainly not all, economic incentives that drive other labor markets. Many Ph.D.s who plan an academic career also accept a temporary postdoctoral research appointment following their degree (in 1987, about one-third of science and engineering Ph.D.s, mostly in the life sciences). This is often a valuable time for new Ph.D.s to immerse themselves in research, free from teaching responsibilities, and prove themselves as full-fledged independent researchers. The postdoctorate is also a labor market buffer, a holding tank for young researchers during a tight market with few tenure-track academic posts and plentiful research dollars.

The level of Federal academic research funding, and the distribution of that funding among fields and research problems, affect both the pregraduate and postgraduate markets. Overall Federal R&D support influences the postgraduate employment outlook for both academic and nonacademic sectors. In addition, Federal policies affecting the economy, e.g., tax policy relating to high-technology industry or industry R&D, also influence the relative growth of employment for doctorates in the private sectors.

The Transition From College to Graduate Study

The transition from college to graduate school dilutes the science and engineering pipeline. Only a few percent of science and engineering baccalaureates continue on for further study.[9] A minority of these enter Ph.D. programs.[10] There are two complementary ways to enhance the supply of Ph.D.s: one is to increase the number of students entering graduate study, the second is to reduce attrition among graduate students and increase the proportion that attain Ph.D.s. Because the Ph.D. population is so small, any small increase in the proportion of college graduates who go on to graduate study would significantly increase the number of Ph.D.s. From the standpoint of the supply of scientists, the most pertinent programs are those that not only encourage graduate school attendance, but also foster graduate study through completion of the Ph.D. Programs to affect Ph.D. productivity must target students contemplating and entering graduate study as well as those already enrolled in graduate school.

Research is still considered by many to be a calling, with modest pay a financial sacrifice that is compensated by other attractive aspects of the research lifestyle. The choice to undertake graduate study is driven by students' career aspirations, their academic performance and confidence, perceptions of the size and stability of the salaries and demand for Ph.D.s, willingness to continue in school another 4 or more years, and the embedded influences of parents, mentors, and peers. One study suggests that natural science students have placed less importance on their financial futures, and worried less about current financial concerns, in their decisions to pursue graduate study than engineering or nonscience students.[11]

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[9] National Science Foundation, *The Science and Engineering Pipeline*, PRA Report 87-2 (Washington, DC: April 1987), pp. 3-4 (based on U.S. Department of Education data from the National Longitudinal Survey and High School & Beyond survey).

[10] And among the cadre to make this important transition are few members of racial and ethnic minorities. For a comparative perspective, by field and race/ethnicity, on the attenuation of talent at this crucial juncture and its implications for the teaching and research work force, see Shirley Vining Brown, *Minorities in the Graduate Education Pipeline: A Research Report of the Minority Graduate Education Project* (Princeton, NJ: Educational Testing Service, 1987), pp. 8-16.

[11] Consortium on Financing Higher Education, *Beyond the Baccalaureate: A Study of Seniors' Post-College Plans at Selected Institutions, With Particular Focus on the Effects*

Nevertheless, when extensive money was available for graduate study and the academic job market was booming, a much greater proportion of B.S. graduates went on for Ph.D.s. Long-term concerns over anticipated earnings and stability of a research career may also affect students' decisions. Many observers also believe that the current generation of students, with higher and more widespread educational debt, may be more strongly deterred from graduate study than previous generations.[12] Although most graduate education is subsidized, especially at the major research universities, graduate study is still a financial struggle and sacrifice, even for students on the most generous fellowships (see box 3-A).

The importance of nonfinancial criteria also shows up in students' choice among Ph.D. programs. Once students have decided to go to graduate school and have been accepted, the research reputation of a department and its faculty as well as financial aid offered determines where they attend. Short-term financial considerations, including anticipated expenses and small differences in financial aid packages offered by different schools, are not decisive in influencing students' choice among graduate schools to which they have been accepted.[13]

During and immediately after the Vietnam War, several economic factors discouraged students from attending graduate school. The two most important were the reduction in stipend support (which increased reliance on loans and lengthened the time to degree, and thus increased foregone income); and a poor labor market, particularly in academia.[14] But graduate enrollments did not decline in the 1970s and 1980s as much as

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of Financial Considerations on Graduate School Attendance (Cambridge, MA: March 1983), pp. 17, 24; and Jerry Davis, Pennsylvania Higher Education Agency, personal communication, April 1988. The small, nonrepresentative survey population was 4,409 seniors at eight Consortium on Financing Higher Education (COFHE) institutions, and 1,910 seniors at three public institutions. Two of the eight COFHE institutions were women's colleges, which skews the results away from a "national average."

[12] Janet S. Hansen, "Student Loans: Are They Overburdening a Generation?" Report for the Joint Economic Committee of the U.S. Congress, mimeo, December 1986, pp. 35-37; and College Scholarship Service, *Proceedings: College Scholarship Service Colloquium on Student Loan Counseling & Debt Management, Dec. 2-4, 1985* (New York, NY: College Entrance Examination Board, 1986).

[13] Margaret E. Boeckmann and Alan L. Porter, "The Doctoral Dissertation in the Biosciences," *BioScience*, vol. 32, No. 4, April 1982, p. 273.

[14] David W. Breneman, *Graduate School Adjustments to the "New Depression" in Higher Education* (Washington, DC: National Board on Graduate Education, February 1975). It is important to remember throughout this discussion that selective service and the brooding presence of a military draft has had profound effects on educational aspirations and the realization of career plans.

expected, for several reasons: students attended graduate school to improve their chances in an uncertain job market, slowed but still rising undergraduate enrollments fueled continuing university demand for Ph.D.-trained faculty and for graduate students to help with teaching and research, more women attended, and many students attended either part time or for nonfinancial reasons, such as the desire to pursue a research career and an academic lifestyle.[15]

Attrition From Graduate Study

Those who embark on doctoral study are highly selected through the formal hurdles of undergraduate study — testing, admission to graduate school, the allocation of financial support, and the personal assessments of faculty who have taught and worked with students as undergraduates. However, attrition is still disturbingly high. Nearly one-half of science and engineering graduate students fail to complete their doctorates. Over the course of years, some find that they do not like research, or go to more financially or socially rewarding or secure work.[16] Some succumb to the rigor of a challenging course of study and research. And the time required to earn a Ph.D. ensures some attrition. Many of those who leave have the potential and interest to become scientists and are in that sense a "real" loss to the research work force (see table 3-1). Yet those who leave use their scientific training in other fields. Many who leave without Ph.D.s stay in the scientific work force as researchers or teachers.

Attrition is surprisingly unpredictable on the basis of typical measures of student quality.[17] It is clear that universities can moderate attrition, not only by helping provide financial support throughout graduate study, but in shaping the rest of the environment, from housing and child care through academic support and advice. Universities have different approaches to "producing the best." Some universities accept only a few graduate students and work hard to see them all through. Others take pride in "washing

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[15] Synder, op. cit, footnote 8.

[16] Penelope Jacks et al., "The ABCs of ABDs: A Study of Incomplete Doctorates," *Improving College and University Teaching*, vol. 31, No. 2, 1982, pp. 74-81. In a survey of students who had left after completing all their work except their dissertation, the authors found that financial difficulties were an important but not dominant reason for leaving. Typically a combination of reasons prompted the decision.

[17] Warren W. Willingham, "Predicting Success in Graduate Education," *Science*, vol. 183, Jan. 25, 1974, pp. 273-278. He reviewed several predictors: undergraduate grade point average (GPA), graduate record examinations (GRE) scores, college faculty recommendations, graduate GPA, performance on departmental examinations, and graduate faculty assessment. The only predictor of success in earning the Ph.D. was performance on the GRE advanced test.

Table 3-1. — Reasons for Leaving Graduate School: A Survey of 25 Ex-Graduate Students

Reasons for leaving doctoral program	Percentage	No. responses (N=70)
Financial (financial problems, good job offer, paid job interefered with thesis work)	39	27
Academic (problems with adviser, thesis research, peers)	36	25
Personal (personal or emotional problems, family demands, loss of interest)	27	19

NOTE: Very little study has been made of "failed" graduate students. This telephone survey was made of 25 advanced graduate students who never completed their dissertation. The students were Ph.D. candidates around 1970 and came from various universities. Their median age when interviewed was 39. Since each of the 25 respondents gave several reasons for leaving, the total number of responses was 70. Financial difficulties were especially cited by married students.

SOURCE: Penelope Jacks et al., "The ABCs of ABDs: A Study of Incomplete Doctorates," *Improving College and University Teaching*, vol. 31, 1982, pp. 74-81.

out" lots of students along the way. Attrition seems to be lower at the top research universities, although it is difficult to say whether that is because these universities get most of the best students, or because they have advantageous financial support and research programs.

Disadvantaged students — minorities, and to a lesser extent women and low-income students — are affected differently by finances in their decisions to attend graduate school. Blacks are significantly more likely to report current financial considerations (the need to improve finances and high debts) as major reasons for not going to graduate school. Minorities unfamiliar with the academic world, particularly Hispanics, may be unaware that graduate education is usually subsidized. Asians, many of whom go on to other professional education, worry less about the appropriateness of advanced education and the cost of graduate study.[18]

FINANCING GRADUATE EDUCATION

Since World War II the demonstrated national importance of R&D scientists and engineers has encouraged national investment in a small and select cadre of highly-educated, mobile graduate students. External support overcomes high costs and economic deterrents to advanced study. The Federal Government, universities, States, foundations, corporations, and other private groups have subsidized science and engineering graduate study not only through support of individual students, but through support for research institutions and important research problems.

Diverse and multiple sources of support are a strength of American graduate education. Each of these providers has different reasons for investing in graduate education, and different criteria and mechanisms for allocating funds. Together, they support a richer variety of students and research problems than any one source would support on its own. Diversity of support also enhances the financial stability of graduate programs.

Graduate education is expensive, including not only tuition, fees, and living expenses, but a student's share of research costs over 4 or more years. It is impossible to calculate exactly the cost of a single student's graduate education, but an estimate of

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[18] Consortium on Financing Higher Education, op. cit., footnote 11, p. 22; Howard G. Adams, "Advanced Degrees for Minority Students in Engineering," *Engineering Education*, vol. 78, No. 8, May 1988, pp. 775-776.

$100,000 is not unreasonable. The tuition and fees charged to graduate students fall short of compensating for the actual burden incurred by the university. But universities and society receive many benefits from graduate students — e.g., immediate and future work as teaching and research assistants. Allocating costs of graduate education between research and instruction is a matter of judgment, not measurement.

Federal and other support at the graduate level has two major purposes: to cultivate a new generation of scientists and engineers to meet national R&D needs, and to buy research and teaching help at the universities. The central tools of this support — fellowships, traineeships, and research assistantships — are usually considered necessary reinvestment and maintenance for research and have very different characteristics from Federal undergraduate aid programs. Graduate support is usually awarded according to merit, and is linked to particular universities, departments, and/or fields and research topics. Most support requires research or teaching labor of graduate students in return for tuition subsidies and stipends.

Funding data show different patterns of support for graduate students in general, and for those who eventually earn Ph.D.s.[19] About one-half of graduate students intending to get a doctorate never earn a Ph.D. Some will earn Ph.D.s, returning research service for the investment of Federal and other external support during their apprenticeship. Because graduate students need support during their training, it is impossible to fund Ph.Ds.; we can only fund prospective Ph.D.s. Certainly some students show outstanding promise; indeed, fellowships are designed to find and support these students. Others, however, do not blossom until later in their careers.

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[19] Information on support of graduate students and of Ph.D.s is collected in different ways and is not completely comparable. Some differences in patterns of support for graduate students and Ph.D.s would be expected, since one measures support for all graduate students (by full time, part time, and type of institution), while the other looks only at that subset of graduate students who make it through to a Ph.D. (About 75,000 new full-time graduate students, only some intending a Ph.D., entered doctorate-granting institutions annually in the late-1970s, and about 19,000 Ph.D.s graduated about 6 to 7 years later.) The most obvious explanation of differences in patterns of graduate student and Ph.D. support would be that successful graduate students (i.e., Ph.D.s) have a certain pattern of support, and unsuccessful ones another. Differences in methodology might account for some differences in the two databases. Graduate student support information is provided by the student's host department in response to National Science Foundation surveys: Ph.D. data are provided by the Ph.D. recipients themselves in the National Research Council's Survey of Earned Doctorates (conducted for the National Science Foundation). It would be helpful to have reliable finanical aid information about graduate students through the course of their doctoral study, from Ph.D. recipients and those who drop out. The Department of Education is conducting an in-depth study of undergraduate and graduate student financing; the results on graduate education are forthcoming.

Sources of Graduate Student Support

Graduate students obtain support from many sources. Most use several sources at one time, including personal funds and spouse's salary, since one form of aid rarely covers tuition, fees, living expenses, and research costs.[20] In addition, the major sources of support often change during the period of graduate study; as most awards are only made for one or a few years, there is an intrinsic instability to the life of a graduate student (see figure 3-2). Most students work during the first 1 or 2 years (or more) as teaching assistants, fulfilling the university's need for undergraduate teaching, while taking classes and developing a thesis topic. Then they may receive a research assistantship or fellowship, which allows them to work in the laboratory full time on thesis-related research. During the early, less focused years of graduate study, the student may not be prepared to benefit from that sort of freedom. Family support and loans are widely used as supplements to primary institutional or Federal support.

The university department is the gatekeeper for nearly all graduate student support funds, including external Federal or corporate funds (see figure 3-3). For example, Federal training grants are awarded to departments, which in turn select the students who will receive traineeships under that large grant. Research support usually goes to individual faculty, or to departments, who then hire graduate students as research assistants. Very few dollars go directly from the funding source to the student without passing through the guiding hands of departmental administrators and faculty, who must evaluate student potential and needs as part of the delivery of graduate education.

Direct Federal support is not the dominant source of funds for graduate students. Institutional support (mostly teaching assistantships (TAs) awarded by the university) and self-support are more common. In 1986, 71 percent of science and engineering graduate students received substantial external support; 41 percent received their primary support from institutions and States, 20 percent from the Federal Government. Other sources of stipends, including corporations and foundations, supported 7 percent of science and engineering students, and foreign sources supported 3 percent (mostly foreign students)

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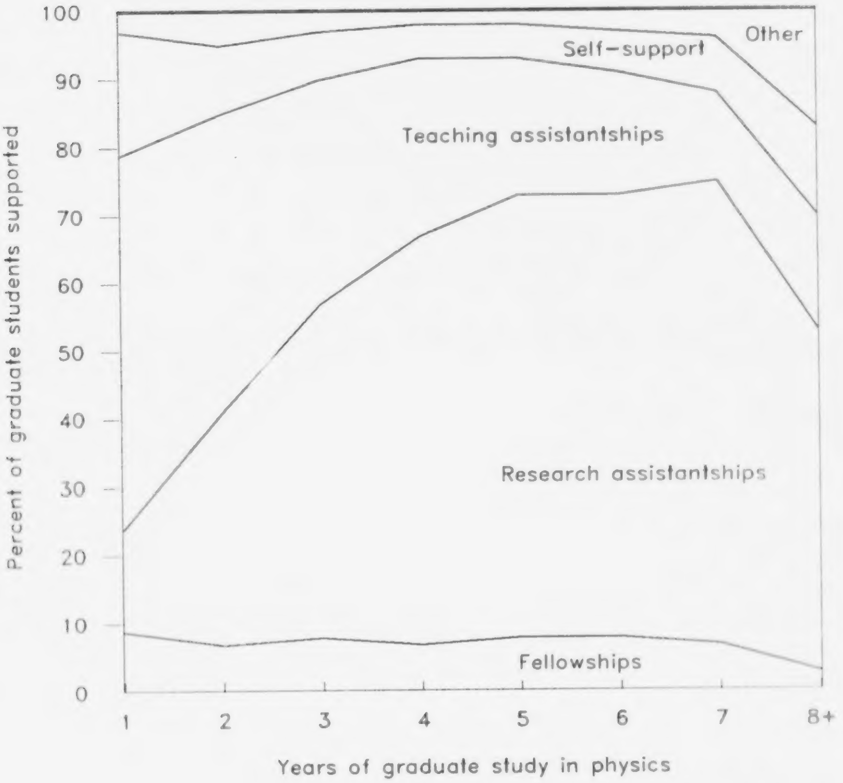
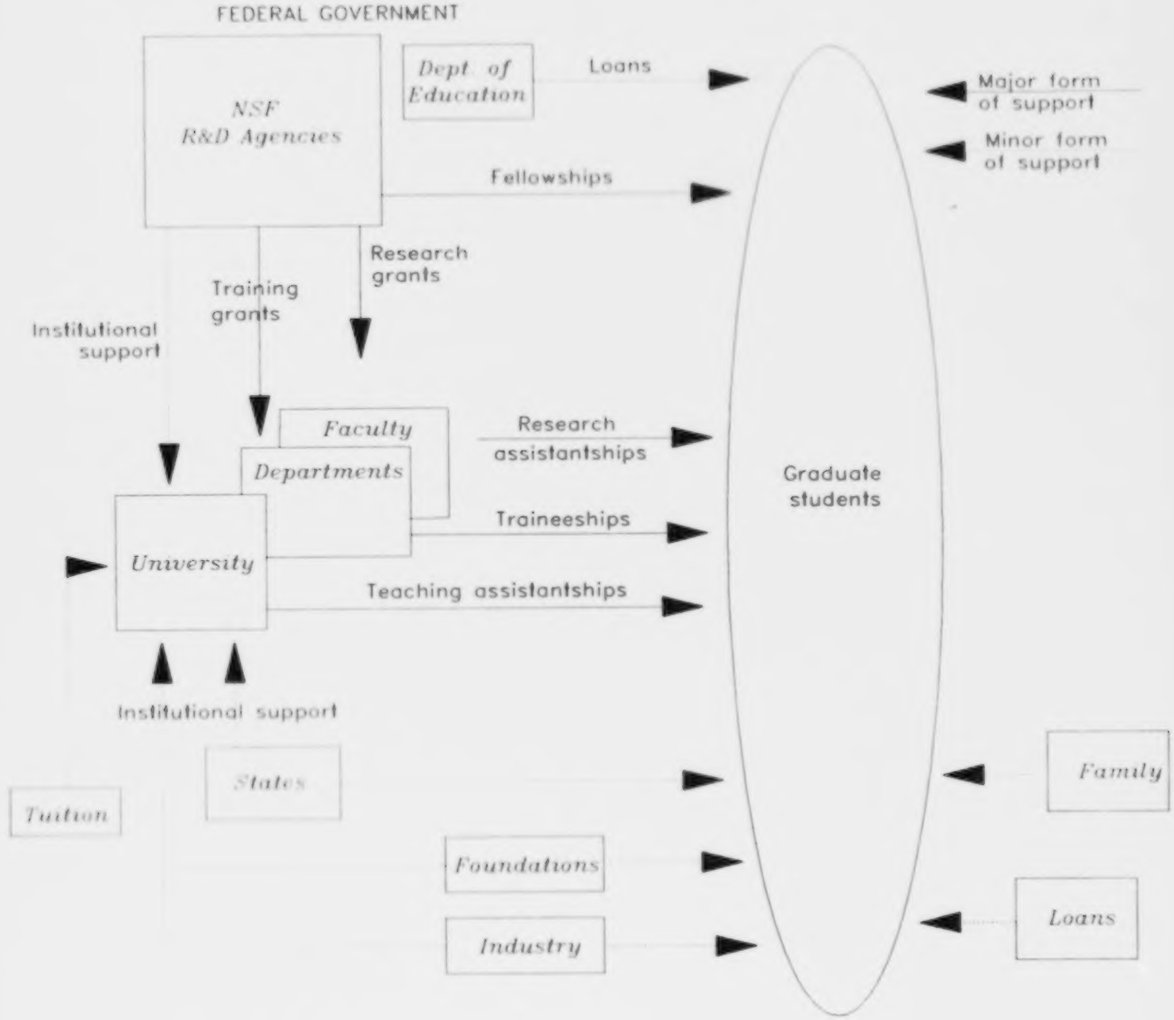
[20] Moonlighting may be an important supplementary source of support. Nothing is known about how much science and engineering graduate students work outside of their graduate programs, but some surely do.

Figure 3-2.—Sources of Support for Graduate Physics Students, by Number of Years of Study, 1986-87 Students



SOURCE: American Institute of Physics, 1986-1987 Graduate Student Survey, Pub. No. R-207-20 (New York, NY: American Institute of Physics, 1988).

Figure 3-3.–Paths of Support for Graduate Education


FEDERAL GOVERNMENT
NSF
R&D Agencies
Dept of Education
Loans
Major form of support
Minor form of support
Fellowships
Research grants
Training grants
Institutional support
Faculty
Departments
Research assistantships
Graduate students
Traineeships
University
Teaching assistantships
Institutional support
States
Tuition
Family
Foundations
Industry
Loans

SOURCE: Office of Technology Assessment, 1988.

(see table 3-2). Twenty-nine percent supported themselves.[21] In the past decade, institutional support, including local and State funding, has grown while Federal support has declined (see figure 3-4).[22] Corporate support has grown slightly; it is the primary source of support for only 1 percent of science and engineering Ph.D.s (see table 3-3).

The availability and type of funding affect successful completion of a Ph.D. There are significant variations, however, by field, gender, and race and ethnicity in the relationship between graduate student funding and completion of science and engineering Ph.D.s. These are explored below.

Federal Support for Graduate Study

About 50,000 science and engineering graduate students depend primarily on Federal support, mostly in the form of fellowships and research assistantships (RAs).[23] This number has fluctuated slightly since the late-1960s, declining to a low of 41,000 in 1973, then climbing slowly to 53,000 in 1980, and receding slightly thereafter (see figure 3-5). Enrollments have risen substantially since then, however, so that despite steady Federal support in numbers of students, the proportion of graduate students with Federal support has declined. This decline has occurred in all fields (see figure 3-6). In 1986, about 20 percent of full-time science and engineering graduate students received the bulk of their support from the Federal Government. (At the peak of Federal support, in 1966, 40 percent received Federal support.)

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[21] National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), p. 138. This is based on full-time graduate students in doctorate-granting institutions. (The distribution is about the same for full-time students in master's-granting institutions, with less Federal and more institutional, self, and other support.) Federal support is focused on the "core" Ph.D.-bound population, full-time students in doctorate-granting institutions. The data are for "primary support," which masks the fact that most students receive support from several sources; many of those who are getting the bulk of their support from Federal sources also may be using family funds, loans, or university aid to make ends meet.

[22] Ibid., p. 138. National Research Council, unpublished data from the Survey of Earned Doctorates. The data are reported by Ph.D.s themselves rather than the department, as is the case with National Science Foundation data on graduate student support. This accounting may lead to understating the extent of Federal support and overstating institutional support.

[23] Ibid., p. 152. Full-time graduate students in doctorate-granting institutions. In 1986, 51,367 (20 percent) received their primary support from the Federal Government. Among full-time students in all institutions, 52,748 (19 percent) were federally supported. Federal support usually is confined to students working full-time for a Ph.D.

Table 3-2. — Graduate Students' Primary Support, by Source of Support and Field, 1986
(in percent)

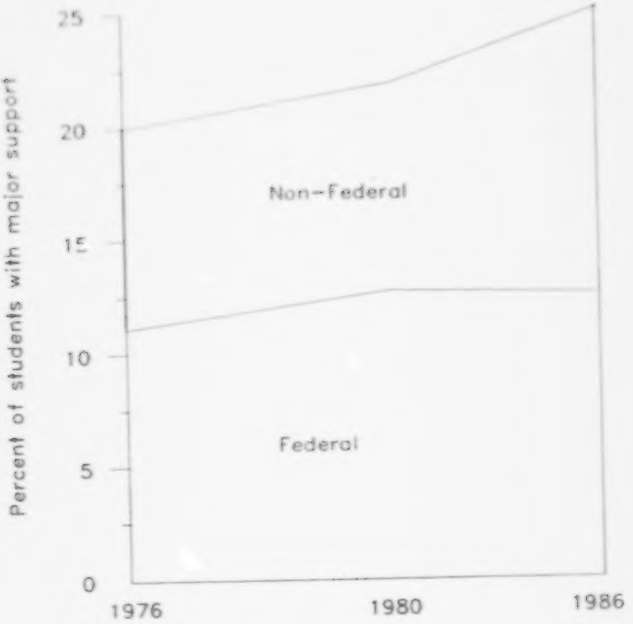
	Institutional[a]	Federal	Personal[b]	Other[c]
Natural Sci/Eng (n=190,384)	40	24	24	11
Science/Engineering (n=259,980)	41	20	29	10
Engineering	33	21	29	17
Computer science	32	13	44	11
Mathematics	70	8	17	5
Physical sciences	52	35	6	7
Earth sciences	38	28	23	11
Life sciences	39	28	24	9
Social sciences	44	7	42	7
Psychology	45	9	40	6

[a] Includes State support.
[b] Includes loans.
[c] Includes corporate and foreign support.

NOTE: Full-time graduate students in doctorate-granting institutions.

SOURCE: National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), p. 49.

Figure 3-4.—Percent of Graduate Students with Major Support by Research Assistantships, Federal and Non-Federal, 1976-86



NOTE: Data for 1978 are interpolated.

SOURCE: National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), pp. 128, 160-161; and National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983*, NSF 85-300 (Washington, DC: 1985), p. 129.

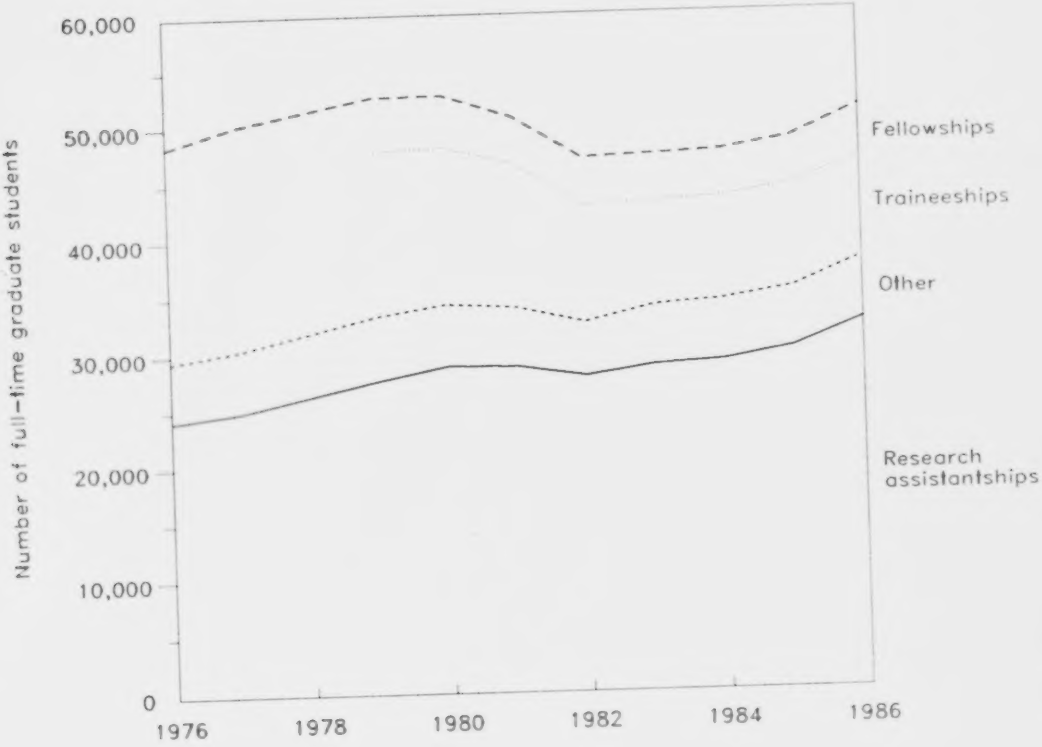
Table 3-3. — Primary Source of Support of Ph.D.s, by Field, 1986
(in percent)

	Institutional[a]	Federal	Personal[b]	Other[c]
All fields (26,232)[d]	45	7	42	6
Science/engineering (16,388)	32	10	28	16
Engineering (2,754)	68	6	16	10
Computer science (340)	58	4	26	12
Mathematics (600)	74	5	14	7
Physical sciences (3,076)	81	5	11	4
Life sciences (4,829)	50	19	24	7
Social sciences (4,789)	38	7	50	5

[a] Includes State support.
[b] Includes loans.
[c] Includes corporate and foreign support.
[d] Number of Ph.D.s reporting source of support (not total Ph.D.s); includes foreign citizens.

SOURCE: National Research Council, unpublished data.

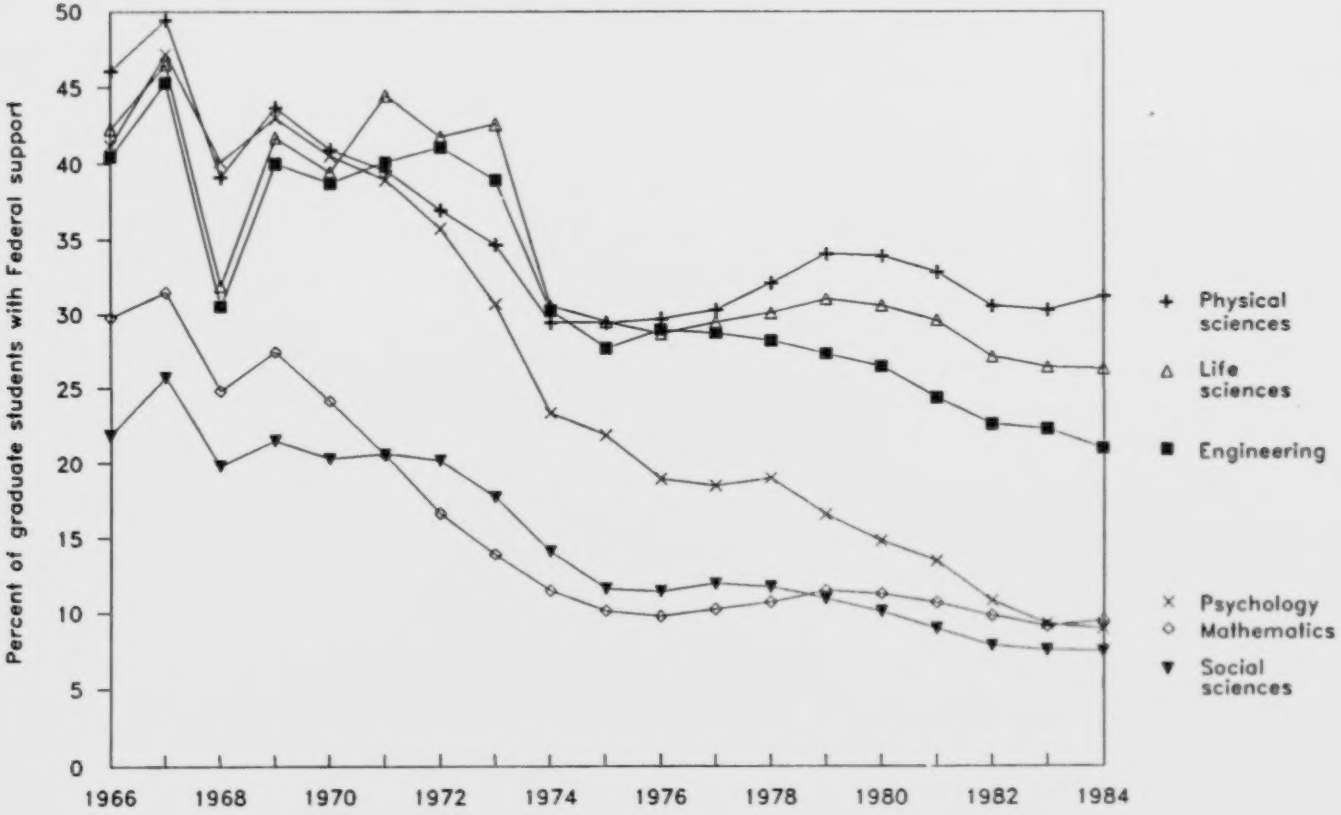
Figure 3-5.-Federal Support of Full-Time Graduate Students in Ph.D.-Granting Institutions by Type, 1976-86



NOTE: Data for 1978 are interpolated.

SOURCE: National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986, NSF 88-307 (Washington, DC: 1988), p. 152; and National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1983, NSF 85-300 (Washington, DC: 1985), p. 129.

Figure 3-6.–Percent of Graduate Students With Federal Support, by Field, 1966–84



SOURCE: Betty M. Vetter and Henry Hertzfeld, "Federal Funding of Science and Engineering Education: Effect on Output of Scientists and Engineers, 1945–1985," OTA contractor report, 1987, based on National Science Foundation data.

Federal support varies by field (see figure 3-7). In the physical sciences, over one-third of graduate students are federally supported. A high proportion of life science students also benefit from Federal support, reflecting long-standing Federal interest in basic biomedical research. In mathematics and social sciences only about 10 percent of graduate students are supported by Federal funds, although for different reasons. Mathematics departments provide a great deal of service teaching, so most graduate students are supported by institutional teaching assistantships.

Mechanisms of Support for Graduate Study

Direct support for graduate students in science and engineering takes four primary forms:

- fellowships awarded, on merit, to individual graduate students by the Federal Government, the university, or private sources;
- traineeships, awarded by departments who have received Federal or other training grants;
- RAs, tied to research grants and contracts awarded to principal investigators in university departments; and
- TAs, awarded by the university in exchange for teaching duties.

Indirect funding comes from private and government grants to support the research and education infrastructure and are awarded to universities, departments, and centers. Another form of indirect funding is State subsidies of public universities. Both types are used for faculty salaries, equipment, facilities, and overhead. Private and federally guaranteed loans provide a supplementary source of assistance to graduate students.

Research Assistantships. RAs linked to research grants are the most important form of support for science and engineering graduate students. RAs typify the apprenticeship model of graduate study: they put students into the laboratory with faculty mentors, placing them on the fast track toward thesis research, a Ph.D., and publications. Although often not considered part of science and engineering education budgets and policies, RAs are the primary support of one-quarter of graduate students and have been used by over one-half of science and engineering Ph.D.s.[24] RAs are

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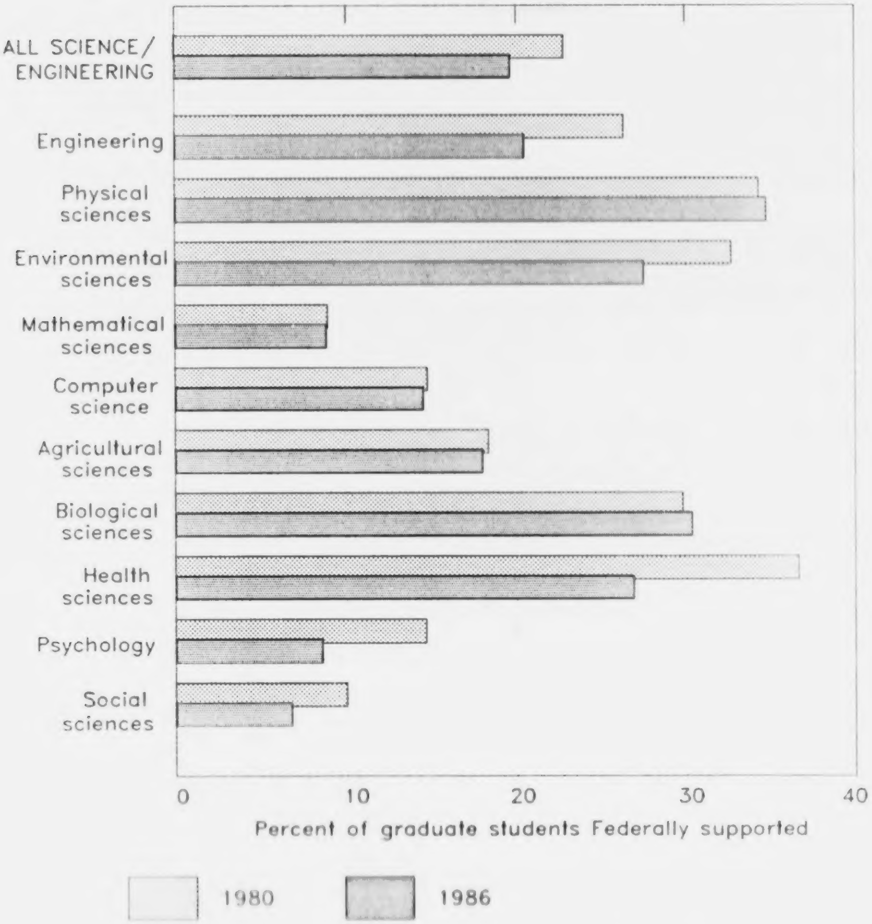
[24] National Science Foundation, op. cit., footnote 21, p. 151 (full-time graduate students in Ph.D.-granting departments); and National Research Council, *Summary Report 1986: Doctorate Recipients From United States Universities* (Washington, DC:

Figure 3-7.—Percent of Federally Supported Graduate Students by Field, 1980 and 1986



SOURCE: National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986, NSF 88-307 (Washington, DC: 1988), pp. 128, 147.

dependent on their mentor to obtain and maintain research funding. Some argue that overreliance on RAs and the reduction of academic research support may channel graduate students' training to those faculty with strong research support; others see no problem, and in any case the current level does not seem to impose undue restrictions.

With the decline in fellowships and traineeships, RAs have become relatively more important. Non-Federal RAs have been growing much faster than Federal RAs. In 1986, for the first time in recent decades, more RAs were supported by non-Federal sources than by the Federal Government. About one-half of RAs are federally funded, although this proportion varies greatly by field. In fields with a strong Federal R&D presence and a research and graduate rather than a teaching and undergraduate orientation, such as physics, more RAs are federally funded. The rest of RAs come, through the department and faculty, from nonfederally funded research projects or institutional funds (see figure 3-8).

Nearly 30,000 science and engineering graduate students work as RAs on Federal funds. National Science Foundation (NSF) research grants support about 10,000 students each year, compared to about 1,500 per year on NSF fellowships.[25] Even at the National Institutes of Health (NIH) with its extensive training grant program, RAs are more widespread than fellowships and traineeships.

Since the decline in Federal fellowships and traineeships beginning in 1970, RAs have by default become a relatively more important source of Federal support. Some worry that overreliance on RAs may reduce opportunities for young graduate students to experiment with different courses and faculty, and may lead to premature specialization, although there is no solid evidence that this is happening.[26]

RAs are disproportionately concentrated in the top doctorate-awarding institutions, which is not surprising given the similar concentration of research funds: 50 universities have one-half of all full-time graduate students and 60 percent of all RA-supported graduate students.[27] As Federal R&D dollars hasten the development of new fields, graduate students and Ph.D.s will follow.[28] However, rising overhead rates at

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National Academy Press, 1987), p. 54.

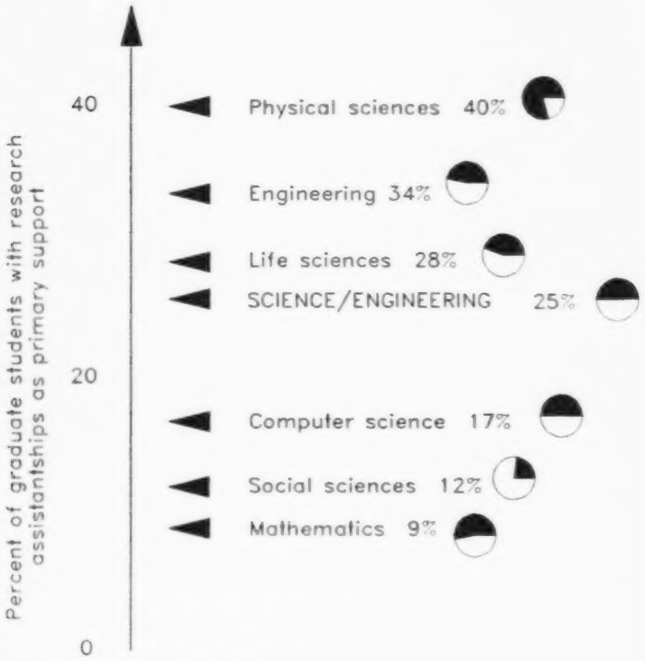
[25] National Science Foundation, Comptroller's Office, unpublished data, 1988.

[26] Snyder, op. cit., footnote 8, p. 36.

[27] National Science Foundation, op. cit., footnote 21.

[28] Susan E. Cozzens (ed.), "Theme Section: Funding and Knowledge Growth," *Social Studies of Science*, vol. 16, No. 1, February 1986, pp. 3-150.

Figure 3-8.—Full-Time Graduate Students With Research Assistantships in Doctorate-Granting Institutions, by Field, 1986



NOTE: Percent of research assistants that are federally supported: 30%

SOURCE: National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986, NSF 88-307 (Washington, DC: 1988), pp. 128, 159-160.

universities may dilute the benefits to graduate education of increased Federal research support, even though universities protect graduate students as much as possible against the ill effects of constrained research budgets.[29]

Fellowships, Training Grants, and Teaching Assistantships. Fellowships and traineeships, with their generous stipends and few strings, are especially important to give students flexibility and time for independent work.

Fellowships are designed as elite mechanisms, to give a few of the "best" generous support and inspire the rest. Federal and private fellowships are awarded directly to the best students, regardless of the institutions they attend, though these students tend to migrate to the major research universities. Fellowship recipients earn their degrees faster and are more likely to join the science and engineering work force than those without such support. Federal fellowships in particular have been a quick and easy way to "buy" new Ph.D.s.[30]

Less than 10 percent of graduate students, however, enjoy fellowship support. The prestige of these awards makes them disproportionately important in providing quality education and in luring students into fellowship areas of study. Fellowships are portable, and require no formal service. Recipients of portable fellowships gravitate to the major research universities, so fellowships tend to enrich the richest institutions. Awards include a generous stipend ($10,000-$20,000) and an institutional allotment.

Most fellowships are awarded for 3 years; the money can usually be used over a longer period of up to 5 years. Some agencies have special dissertation support fellowships, usually awarded for 1 year. Many also have programs that encourage graduate students to spend a summer doing research at a government laboratory. Most agencies also have postdoctoral fellowships and/or research associateships.

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[29] Graduate students benefit more from individual investigator grants than any other form of support. About 5 to 15 percent of the average research grant to an individual investigator goes to graduate research assistantships (RAs), though the proportion varies by field and by funding agency. National Science Foundation grants support more, and the Department of Defense fewer, RAs per research grant dollar. Information based on personal communications with agency program officers.

[30] See U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School*, OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988), pp. 78-80.

The Federal Government supported about 4,500 graduate fellows in 1986, about 20 percent of all graduate fellows.[31] The number has been increasing in the past few years, although it is still below the annual level of 5,000 in the late-1970s, and the peak of nearly 12,000 in 1969. Federal fellowships constitute only a tiny amount of all Federal support, and reach less than 2 percent of graduate students. Many agencies have recently increased their fellowship stipends to attract more students, and to compensate for recent moves to tax fellowships.

Training grants are awarded, through national competition on the basis of merit, to institutions or departments for training in specific areas. They are usually multiyear packages covering faculty salaries, seminars, supplies, equipment, and predoctoral and postdoctoral student stipends. The institutions select the graduate students who receive traineeships. The Federal Government supports about 60 percent of them.[32]

The life sciences rely heavily on training grants, which NIH uses as its major mechanism of support. About 18 percent of life science Ph.D.s received NIH training grants.[33] Such grants, however, offer lower than average stipends. A payback provision in NIH's National Research Service Awards is designed to keep supported Ph.D.s in research.[34]

An NIH-sponsored study of training grants emphasize their multiple benefits for training as well as departmental and institutional development:[35]

- They support the research training environment for students, including research supplies and guest faculty seminars.

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[31] National Science Foundation, op. cit., footnote 21, p. 152. The numbers refer to full-time graduate students in Ph.D.-granting institutions with Federal fellowships as their primary source of support. (Because of their size, fellowships are always the primary source of support.)

[32] Ibid., pp. 156-157.

[33] National Research Council, unpublished data from the 1987 Survey of Earned Doctorates. This has been fairly stable over the past 5 years.

[34] National Science Foundation (NSF) training grants assisted institutional development and expansion in the 1960s, but no longer exist. From 1964 to 1973, NSF training grants supported over 8,000 students. U.S. Congress, General Accounting Office, *University Funding Mechanisms: Federal Funding Mechanisms in Support of University Research*, GAO/RCED-86-53 (Washington, DC: February 1986), p. 110.

[35] Commission on Human Resources, National Research Council, Committee on a Study of National Needs for Biomedical and Behavioral Research Personnel, *Personnel Needs and Training for Biomedical and Behavioral Research, 1981 Report* (Washington, DC: National Academy Press, 1981), pp. 7-10, 74-76.

- They permit a high degree of student choice in sampling courses and faculty, more so than RAs tied to individual research projects.
- They foster broad basic training rather than premature specialization.
- They create institutional continuity and a focus on graduate training.

According to this study, recipients of traineeships were more apt than nontrainees to complete their degrees, enter research careers, and publish.[36] Although the grant recipients studied were a select group of NIH trainees and thus might be expected to perform above average with any support, it does show that the traineeship system — the nature of the training grant and the selection process used to identify recipient institutions and students — succeeds in training highly able researchers.[37]

Teaching assistantships are awarded by the university in direct exchange for a student's help in teaching one or more undergraduate courses. TAs are the primary source of support for a little over 20 percent of full-time graduate students. They are used quite widely; over one-half of science and engineering Ph.D.s report that they held a TA during their studies. Mathematics graduate students are particularly heavy users of TAs because of the heavy demand on mathematics departments to provide "service" instruction for undergraduate and graduate students in almost every field of study. Mathematics graduate students receive fewer RAs and fellowships. The Federal Government awards less than 1 percent of TAs, about 500 annually, most in the life and social sciences. The number of federally funded TAs has declined, while overall TAs have risen.[38]

Although widely used, especially during the early years of graduate school, TAs are less desired by students than RAs or fellowships. Students do not get as much "career credit" for TAs even though they may gain useful experience and provide valuable service in the classroom and laboratory. Teaching takes time away from the graduate student's research, and graduate students may not be able to teach a subject directly related to their work. At worst, they indenture students, prolong graduate study, and highlight the tension between research and teaching on campus. However, TAs provide valuable teacher training for the student. Too little is made of the value of apprentice teaching: well-supported TAs can draw attention to teaching as part of graduate training, encourage good service teaching at universities, and provide female or minority role models for undergraduates.

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[36] Porter Coggeshall and Prudence W. Brown, *The Career Achievements of NIH Predoctoral Trainees and Fellows* (Washington, DC: National Academy Press, 1984). A similar study was conducted on National Institutes of Health postdoctoral trainees: Howard H. Garrison and Prudence W. Brown, *The Career Achievements of NIH Postdoctoral Trainees and Fellows* (Washington, DC: National Academy Press, 1986).

[37] The same study reported that cutbacks in institutional training grants result in reduced opportunities for seminars and travel to professional meetings, and a narrowing of students' choices of mentors to those who have research grant support, thus eliminating from consideration young faculty who have yet to receive such awards. Coggeshall and Brown, op. cit., footnote 36.

[38] National Science Foundation, op. cit, footnote 21, p. 163.

About 30 percent of graduate students are primarily self-supporting, mostly with their own earnings and family savings, supplemented by loans. This is up from about 20 percent in 1969. Borrowing is a subsidiary source of support for most graduate science students. Graduate students tend to borrow in the first 3 years of their study, then turn to research support, while students in the professions (i.e., medicine and law) borrow consistently through their periods of study. Most borrowing is done by full-time students.[39]

Loan use has risen substantially. Loans were used by about one-third of 1987 Ph.D. recipients, compared to 12 percent in 1972. There is no good data on the extent of borrowing and the amount of debt incurred during graduate school.[40] Overall, the number of graduate and professional postbaccalaureate students who borrowed under the Guaranteed Student Loan program tripled from 1977 to 1983, and their average total indebtedness rose from $4,882 to $10,244.[41]

Reliance on self-support varies greatly by field, from only a few percent in the physical sciences to over 40 percent in computer sciences and the social sciences (see figure 3-9). In particular, the extent of borrowing and amount of debt incurred vary by field, being lowest in the physical sciences and highest in the social sciences, and reflecting the greater availability of stipend support in the natural sciences.[42]

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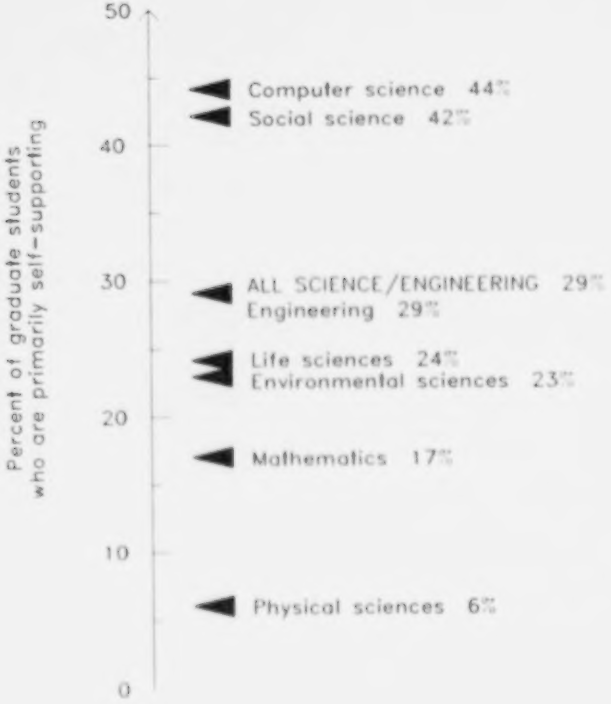
39. National Council on Student Financial Assistance, op. cit., footnote 7, p. 69. Students in historically Black colleges and universities (HBCUs) are much more likely to support themselves; among full-time students in HBCUs, 44 percent are self-supporting v. 31 percent of full-time students in all institutions (National Science Foundation, op. cit., footnote 21, pp. 42, 64).

40. Analysis of data from the Department of Education survey on graduate student financing are forthcoming. By comparison, a 1965 National Center for Education Statistics survey indicated that loans accounted for only 3.5 percent of full-time graduate student budgets (in all fields).

41. Pennsylvania Higher Education Assistance Agency, unpublished data, 1987.

42. Hauptman, op. cit., footnote 7, pp. 74-83; National Science Foundation, op. cit., footnote 21; and Herbert J. Flamer et al., *Talented and Needy Graduate and Professional*

Figure 3-9.—Self-Supporting Full-Time Graduate Students in Doctorate-Granting Institutions, by Field, 1986



SOURCE: National Science Foundation, Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986, NSF 88-307 (Washington, DC: 1988), pp. 138-140.

The Leading Federal Role

The Federal Government plays a leading role in supporting graduate education and influencing the supply of science and engineering Ph.D.s. This is accomplished most directly through support for graduate students via fellowships, traineeships, RAs, and loans.

Federal R&D spending has a twofold pull on graduate education and is overall the most important influence on the size of the future science and engineering work force. It both creates a job market and provides direct support for graduate students in the form of RAs. Graduate enrollments and Ph.D. awards follow large changes in Federal R&D spending, although it is not clear how closely they track small changes.[43] Many other Federal research and higher education programs affect the demand for and quality of graduate education, and are therefore part of graduate education policy. And many other Federal tax, industry, and research policies, as well as immigration and civil rights legislation, have indirect influence by affecting the health and demographics of higher education and private investments in university research, graduate education, and Ph.D. employment.

Students: A National Survey of People Who Applied for Need-Based Financial Aid to Attend Graduate or Professional School in 1980-81 (Princeton, NJ: Educational Testing Service, April 1982). What do such field differences suggest: greater commitment by students whose salary prospects are lower though their incurred debt is higher, or merely lower expectations for remuneration? And is field-switching from baccalaureate to doctorate an indicator of flagged commitment? John W. Sommer, National Science Foundation, personal communication, November 1988.

43. Betty M. Vetter and Henry Hertzfeld, "Federal Funding of Science and Engineering Education: Effect on Output of Scientists and Engineers, 1945-1985," OTA contractor report, 1987. In the early 1960s, under the pro-science administrations of Kennedy and Johnson, the White House and the Bureau of the Budget applied a rule of thumb for R&D budgets that a 1 percent increase in graduate enrollments implied a 1 percent increase in academic research, plus an additional budget boost for "increased sophistication of research." In those days (the reverse of the current situation), the push of expanding higher education enrollments, rather than the pull of national demand for R&D, dominated research training and academic support policy. Harvey A. Averch, *A Strategic Analysis of Science & Technology Policy* (Baltimore, MD: The Johns Hopkins Univesity Press, 1985), p. 80.

TRENDS IN FEDERAL SUPPORT OF GRADUATE EDUCATION

The makeup of the Federal portfolio of graduate student support has changed over the decades. In the past 15 years, Federal support of graduate education has shifted from direct fellowship and traineeship support to indirect support to RAs through academic research grants.

Federal aid, like all financial aid, encourages graduate school application, acceptance, and attendance.[44] Past increases in Federal support boosted graduate school enrollment and Ph.D. production. Pulled into the university by the Vietnam War push, college graduates of the mid-1960s were more likely to go on to graduate study in general, and doctorate programs in particular. This pattern holds for the best students as well.[45]

Graduate study has expanded greatly since World War II, in response to the pull of industry and academia for Ph.D. researchers and faculty, and the pressure of more college graduates seeking further education. As Federal R&D increased, so did the number of graduate students supported on Federal research assistantships, fellowships, and traineeships.

The Boom: 1959-1971

Graduate enrollments and doctorate production in science and engineering rose rapidly during the 1960s, as they did in all fields. Graduate enrollments in all fields more than doubled between 1958 and 1968, and Ph.D. awards tripled; one-fifth of baccalaureates went on to graduate school in 1955, compared to one-third in the peak years of 1967-68.

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[44] C. Ethington and J. Smart, "Persistence to Graduate Education," *Research in Higher Education*, vol. 24, 1986, pp. 287-303; and Vetter and Hertzfeld, op. cit., footnote 43.

[45] Frank Goldberg and Roy A. Koenigsknecht, *The Highest Achievers: Post-Baccalaureate Enrollment of Four Classes Between 1956 and 1981* (Evanston, IL: Northwestern University, Consortium on Financing Higher Education, January 1985), p. 17. The survey encompassed several hundred "high-achieving" students (the top 3 to 5 percent) and a control group from eight selective institutions. In this study of the boom and bust in Federal support for graduate education, doctoral enrollments rose significantly from 1956 to 1966, then dropped by 1976. Among the high achievers, all the increase in 1966 was in doctoral enrollments; master's enrollments actually declined, suggesting that students were more likely to go on not only to postbaccalaureate study, but also to doctoral programs. Doctoral enrollments rose the fastest, and fell the fastest. The control group, on the other hand, slightly increased its postbaccalaureate enrollment, but the increase was all in master's programs.

Graduate enrollments increased faster than simple demographic changes alone would account for. Healthy academic and industrial demand accounts for some of this increase, but the greater availability of stipends certainly enhanced the attractiveness of graduate school. Rapidly increasing Federal support pulled doctorate production along with it.[46]

This growth in education and research was launched with Sputnik, fueled by the Apollo program, and driven later by social goals such as equitable access. During this "golden era" of academic research and graduate education, Federal R&D spending doubled (in constant dollars). The National Defense Education Act of 1958 training grants program supported several thousand Ph.D.s who went on to productive careers in research and technical management (see box 3-B). Until the Apollo program was scaled down in 1967, Federal support of academic R&D increased by about 20 percent a year (in constant dollars), and the number of graduate students (in all fields) on Federal fellowships and traineeships rose from under 10,000 to over 50,000.

While Federal support for graduate study fueled this expansion, it was made possible by the swelling postwar pool of college-educated people. Ph.D. awards declined after Federal fellowships were cut back in 1969, despite continued high undergraduate enrollments. This suggests that the Ph.D. job market booms created by Federal and other research and education funding drove science and engineering graduate study more than did the sheer number of available students. Demand for Ph.D.s rose much faster than the rest of the labor market. Ph.D. production is indeed tied not to demographic trends but to the labor market for researchers.[47] Both the decline in R&D demand and the decline in Federal graduate support contributed to the slowdown in graduate study and Ph.D. production, although it is difficult to quantify the relative effect of the two.

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[46] Snyder, op. cit., footnote 8, p. 20.

[47] U.S. Congress, Office of Technology Assessment, *Demographic Trends and the Scientific and Engineering Work Force*, OTA-SET-TM-35 (Washington, DC: U.S. Government Printing Office, December 1985), p. 41.

After the Boom

The boom, of course, had to end. Social and political priorities shifted away from Cold War-inspired science. In addition, many of the goals of the buildup — increased graduate enrollment and Ph.D.s, university development, faculty expansion, and increased R&D — had been achieved. From 1968 to 1974, the number of Federal Government fellowships and traineeships (in all fields) plummeted 85 percent[48] The number of Federal RAs dropped slightly, owing to a decline in Federal R&D support (in constant dollars). In the first years of the 1970s, first-year graduate enrollments plateaued after a decade of substantial annual increases.

By 1974 the proportion of graduate students relying on Federal support had dropped to 25 percent from the 1969 peak of nearly 40 percent. Infrastructure support was severely curtailed and science development programs were eliminated. Federal support retrenched to a more modest, though still substantial, level.[49]

The cutbacks differed among fields:

- Engineering and physical science were the most affected. Fellowships and traineeships dropped 90 percent, from 13,600 in 1969 to 1,500 in 1975, and National Aeronautics and Space Administration (NASA), Department of Defense (DoD), and Atomic Energy Commission (AEC) research funds dropped 45 percent in real terms. Graduate enrollments and then Ph.D. production declined steadily for 6 years.
- The life sciences were less affected. Fellowships and traineeships declined by nearly 45 percent, but NIH and NSF research funds increased in real terms, mitigating the effects of the fellowship decline. Graduate enrollments and Ph.D.s held steady.
- Least affected were the social sciences. Although fellowship and traineeship support declined by two-thirds, graduate enrollments and Ph.D.s continued to increase slowly.[50]

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48. Richard B. Freeman and David W. Breneman, "Forecasting the Ph.D. Labor Market: Pitfalls for Policy," A Technical Report presented to the National Board on Graduate Education, Washington, DC, April 1974, pp. 12-13.
49. Snyder, op. cit., footnote 8, p. 16.
50. Ibid., pp. 31-32.

As Federal research spending picked up again in the 1970s, demand for research assistants went up and science and engineering graduate enrollments followed suit, but by varying degrees. Nearly all the early increases were in fields affected by funding for the War on Cancer. In the late-1970s, graduate science and engineering enrollments grew moderately and steadily. In the lively computer, semiconductor, and energy markets of the late-1970s and early-1980s, engineering became the fastest growing field. Enrollments in general grew in response to the job market, even though the numbers of graduate students with Federal support declined.

Increasing women's participation helped maintain graduate enrollments in the life and social sciences during this time. Universities resisted cutting faculty, departments, programs, or students in the face of budget cuts. Continued high undergraduate enrollments maintained demand for graduate students as teaching assistants.

Effects of Federal Support

Since to a great extent the ultimate source of funding is "invisible" to the graduate student, whether their time and research supplies are paid for by the Federal Government or a corporation, the effects of a Federal fellowship or assistantship are to some extent similar to a fellowship or assistantship from any source. (And it must be remembered that most Federal support is distributed by the university.) However, Federal support often provides unique value insofar as it

- targets different or unique research problems that other funding does not support;
- provides more (or less) freedom in the recipient's activities and in choosing a research problem, although this freedom may be curbed by work on the research program of the student's mentor;
- targets a category of students or faculty (such as NSF's minority fellowships and program for women re-entering the research work force);
- targets an underserved region or type of institution (such as the historically Black colleges and universities);
- is attended by particular national or scientific prestige (such as the few and prized NSF fellowships); and
- includes access to Federal researchers, equipment, or facilities, such as the national laboratories or NASA facilities.

Federal support has several positive effects on science and engineering graduate students. First, it increases the number of science and engineering Ph.D.s.[51] Graduate science and engineering enrollment and Ph.D.s follow the pattern of Federal support for R&D and students. Graduate enrollments, then Ph.D.s conferred, rose during the 1960s, then turned down abruptly around 1970. During the 1970s, a comparable pattern emerged: the proportion of graduate students with Federal support declined beginning in 1971, and the number of Ph.D. awards declined beginning in 1974.

Second, Federal support encourages full-time study and shortens the time from B.S. to Ph.D.[52] During the boom in Federal fellowship/traineeship/RA support in the late-1960s, the average time from B.S. to Ph.D. declined, and the proportion of graduate students attending full time rose substantially. Since 1970 the time to Ph.D. has been steadily rising, from 6.6 years in 1970, to an all-time high of 8.6 years in 1987,[53] and the proportion of part-time graduate students rose (see figure 3-10). Although it is hard to say which is cause and which effect, as Federal support declined, graduate students were more likely to attend part time and on average took longer to get their Ph.D.s. Fellowships and traineeships, with minimal service requirements, provide students the financial freedom to concentrate on studies full time and the intellectual freedom to immerse themselves in the study and research that earns a Ph.D. Social science students, with the longest time to Ph.D., have the highest dependence on TAs and self-support, and the fewest RAs.

The close links between direct support and Ph.D. awards suggest that Federal support is vitally important to completion of a Ph.D. It is possible that a large portion of the increase in graduate enrollment, in some sense excessive in light of the much smaller increase in Ph.D. awards, is driven by the increase in baccalaureates awarded. The increase in graduate enrollments that began in 1974 follow an increase in science and

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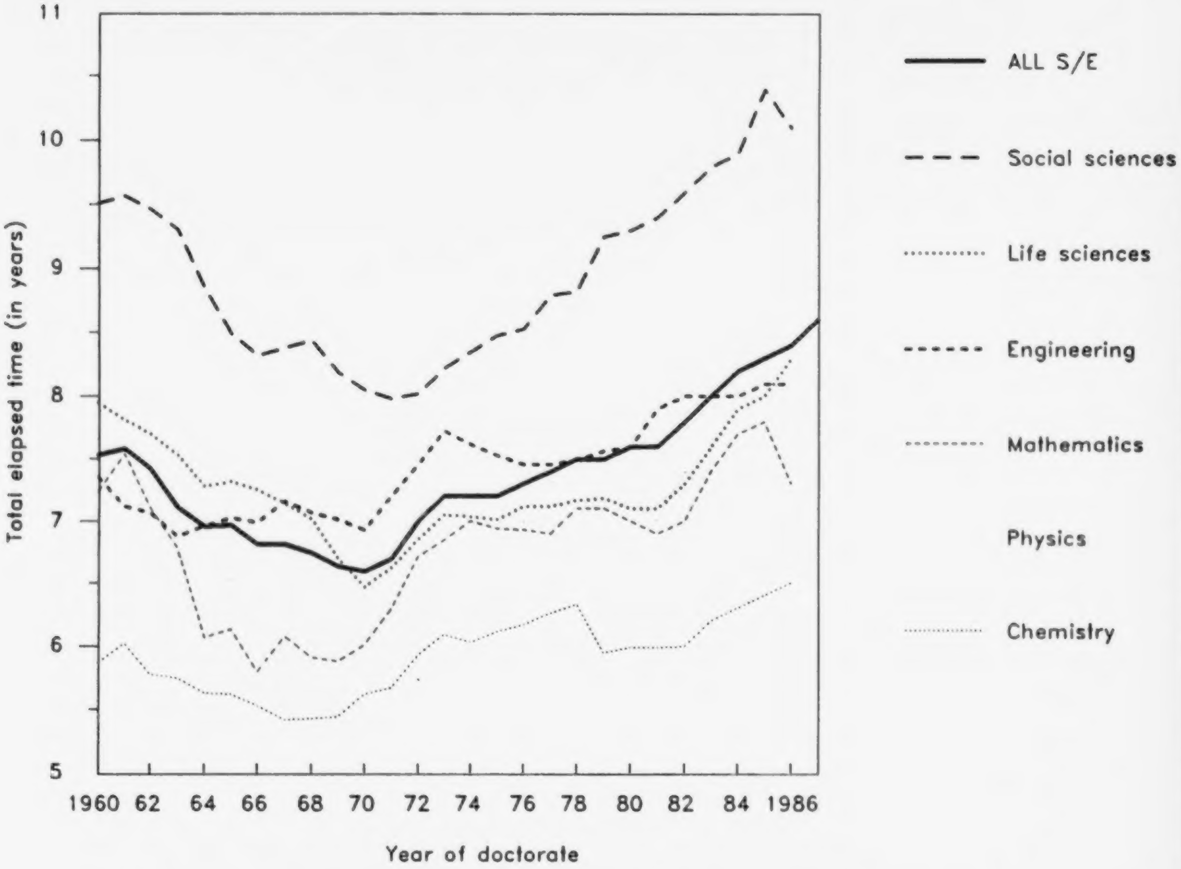
[51] Vetter and Hertzfeld, op. cit., footnote 43, p. 34.

[52] Ibid; and Richard Freeman, *The Market for College Trained Manpower* (Cambridge, MA: Harvard University Press, 1971), developed a model which related a 1 percent increase in the availability of fellowships to a 7.5 percent decrease in B.S. to Ph.D. time lapse. Also see Snyder, op. cit., footnote 8, p. 21.

[53] National Research Council, Survey of Earned Doctorates, unpublished 1987 data. Registered time, 6.4 years for 1987 science and engineering Ph.D.s, has also been increasing.

Figure 3-10.–Elapsed Time Between B.S. and Ph.D., by Field, 1960–87



SOURCE: National Science Foundation, Science and Engineering Doctorates: 1960–86, NSF 88–309 (Washington, DC: 1988), pp. 128–9; and National Science Foundation, Science and Engineering Doctorates: 1960–82, NSF 83–328 (Washington, DC: 1983), p. 80.

engineering bachelor's graduates up to that time. The greatest increase in bachelor's graduates was among women and minorities; this same shift showed up in increased graduate enrollments.

Third, Federal support appears especially effective in helping women complete graduate study. Financial support is especially important for women, although a supportive environment may be more instrumental to success. Females completing Ph.D.s are more likely to have received Federal support, and female graduate students less likely, than their male counterparts (see box 3-C).[54]

Several studies further indicate that fellowships attract graduate students that might otherwise go to professional school, and that a decline in fellowships diverts students from Ph.D. study to professional school.[55] The Consortium on Financing Higher Education survey of eight selective institutions supports this conclusion: from 1956 to 1976, high-achieving students (in all fields) enrolled in postbaccalaureate education in steady proportions (85 percent), but there was a large shift from graduate school to professional school between survey dates 1966 to 1976 (as graduate school enrollment dropped from 54 percent to 35 percent, professional school enrollment rose from 33 percent to 53 percent).[56]

The mission research agencies play a major role in supporting graduate students; four out of five federally funded graduate students are supported by the mission agencies rather than NSF (see table 3-4). Mission agency prominence is due to RAs from agency university research grants. The NIH traineeship program is by far the single largest Federal graduate support program. Department of Education fellowships, though smaller in amount than most mission agency fellowships and not restricted to science and engineering, are used by many women and minority graduate students in science and engineering, particularly in the social sciences.

The largest Federal traineeship or fellowship program is NIH's National Research Service Awards training grants; the approximately $100 million spent on about 5,000 to 6,000 graduate trainees within that program is about 3 percent of NIH's research budget. Among the most prestigious Federal awards are NSF fellowships, which support

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[54] Vetter and Hertzfeld, op. cit., footnote 43, p. 33.
[55] Julia A. Heath and Howard P. Tuckman, "The Effects of Tuition Level and Financial Aid on the Demand for Undergraduate and Advanced Terminal Degrees," *Economics of Education Review*, vol. 6, No. 3, 1987, pp. 227-238.
[56] Consortium on Financing Higher Education, op. cit., footnote 11.

Table 3-4. — Federal Fellowships and Traineeships, by Agency and Field, 1986

Agency	$	Full-time students, 1986
NIH/HHS	$204,339	8,335
NSF	25,152	1,545
Defense	518	378
NASA	7,920	[a]
EPA	2,809	[a]
Energy	550	[a]
Agriculture	4,679	[a]
Other	229	3,074
Total Federal	$246,196	13,332

Field	$	Full-time students, 1986
Life sciences	$192,038	8,923
Psychology	13,795	622
Engineering	10,797	1,005
Social Sciences	10,501	1,630
Mathematics	4,069	146
Chemistry	3,500	326
Environmental sciences	2,438	263
Physics	3,707	253
Computer sciences	500	164
Other	4,851	
Total Science/engineering	$246,196	13,332

[a] Agency total is included in "Other."

Key: NIH/HHS = National Institutes of Health/Health and Human Services
NSF = National Science Foundation
NASA = National Aeronautics and Space Administration
EPA = Environmental Protection Agency

SOURCE: National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), pp. 154, 157; and National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions, Fiscal Year 1986*, NSF 87-318 (Washington, DC 1987), pp. 17, 23.

1,400 graduate students. Among other agencies, DoD, NASA, and the Department of Energy (DOE) are notable for their smaller fellowship and research support programs which bring students into agency and national laboratories. Several agencies, notably NIH and NSF, have special fellowships for minority students.

A consortium of universities, large companies, and government agencies (including DOE, the National Institute of Standards and Technology, and NASA) has started a new program, the National Physical Sciences Consortium for Graduate Degrees for Women and Minorities, to encourage women and minorities to complete Ph.D.s in science or engineering. Program sponsors each contribute something: universities cover tuition and fees, and companies and agencies provide student stipends and research opportunities.

Effects on Women

Women received about 27 percent of science and engineering Ph.D.s in 1987, but this varies greatly by field, from less than 10 percent in engineering to nearly one-half in the social sciences (see table 3-5).[57] The pattern of women's financial support is shaped by their choice of fields. Within any given field, the distribution of graduate student support varies little by sex (see table 3-6). But since women tend to concentrate in fields such as the social and life sciences, where RAs are less common than in other fields, women are substantially less likely to receive RAs.[58]

Women who earn Ph.D.s are actually more likely than men to have received NSF fellowships, NIH traineeships, and other Federal support in graduate school (see table 3-7). But full-time female graduate students are less likely to have Federal support (table 3-8). This may indicate that Federal support is particularly important for women to complete graduate study, although comparing data from two different surveys is risky. Women's propensity to attend part time further constrains their access to support.

Improving the participation of women in science and engineering demands effort on all fronts (see box 3-D). Programs dedicated to female science and engineering students include NSF's Research Opportunities for Women, which supports women scientists and engineers who have not yet been principal investigators or who are reentering the

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[57] National Research Council, Survey of Doctorate Recipients, unpublished 1987 data; U.S. Congress, Office of Technology Assessment, "Preparing for Science and Engineering Careers: Field-Level Profiles," Staff Paper, January 1987.

[58] National Research Council, *Summary Report 1984: Doctorate Recipients From United States Universities* (Washington, DC: National Academy Press, 1986), p. 40.

Table 3-5. — Science/Engineering Ph.D.s by Sex, Citizenship, and Field, 1987

	Women as percent of all Ph.D.s	U.S. women as percent of U.S. Ph.D.s[a]
Science/engineering	27	32
Engineering	7	10
Computer science	14	22
Life sciences	35	40
Social sciences	43	51

[a] "U.S." includes both U.S. citizens and foreign citizens on permanent visas (6 percent), and unknown citizenship (about 7 percent) of total.

SOURCE: National Research Council, Survey of Doctorate Recipients, unpublished 1987 data.

Table 3-6. — Selected Forms of Support for Ph.D.s, By Sex, 1986
(in percent)

	NIH traineeship/ NSF Fellowship		Research assistantship		Teaching assistantship		Own earnings		University fellowships	
	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
All Science/engineering	10	16	61	48	53	52	46	55	21	24
Natural science/ engineering	10	22	67	57	51	49	39	43	20	23
Physical sciences	6	7	72	71	70	72	34	32	22	22
Life sciences	21	29	56	50	39	40	45	48	20	23
Social sciences	8	10	38	37	58	54	67	69	26	24
Engineering	4	9	74	71	42	47	38	38	17	29

NOTE: Type of support not exclusive. Includes foreign citizens, most of whom are male.

Key: NIH = National Institutes of Health
NSF = National Science Foundation

SOURCE: National Research Council, *Summary Report 1986, Doctorate Recipients From United States Universities* (Washington, DC: National Academy Press, 1988), p. 54.

Table 3-7. — Science/Engineering Ph.D.s' Major Source of Support During Graduate Study, by Field and Sex, 1986
(in percent)

	Federal		Institutional		Other		Self[a]	
	Men	Women	Men	Women	Men	Women	Men	Women
Engineering	8	6	61	69	7	8	23	17
Physical sciences	6	8	77	73	3	4	14	15
Life sciences	21	24	55	45	2	2	22	29
Social sciences	8	9	35	35	2	2	55	54

[a] Includes loans, which are primary support for less than 1 percent of Ph.D.s., except in the social sciences, where loans are primary support for about 7 percent of Ph.D.s.

NOTE: Financing data are self-reported This may lead to understating Federal and overstating institutional support, because some students may not know of the original source of department-distributed money. Percentages may not sum to 100 because of rounding.

SOURCE: National Research Council, *Summary Report 1986, Doctorate Recipients From United States Universities* (Washington, DC: National Academy Press, 1988), p. 25, and unpublished data.

Table 3-8. — Science and Engineering Graduate Students' Primary Source of Support, by Field and Sex, 1986
(in percent)

	S/E TOTAL		Engineering		Physical		Math/CS		Life		Social	
	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
All Federal	21	18	21	18	34	29	12	7	26	29	7	8
DoD, NSF, NIH	14	13	13	11	24	21	10	6	19	23	3	4
Other Federal	7	5	8	7	10	8	2	1	7	6	4	4
Institutional	41	41	33	35	47	51	48	53	42	36	45	43
Other U.S.	8	6	14	13	7	6	6	5	7	5	5	4
Foreign	4	1	4	2	2	1	3	2	5	2	4	1
Self	26	33	29	31	11	12	31	34	19	28	39	44

NOTE: Full-time in doctorate-granting institutions. Includes foreign citizens. Physical sciences includes physics, chemistry, and environmental sciences.

Key: S/E = Science/engineering
Math/CS = Mathematics/computer science
DoD = Department of Defense
NSF = National Science Foundation
NIH = National Institutes of Health

SOURCE: National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), pp.141-146.

research community. Many professional societies have established special committees on women.

Effects on Minorities

The participation of Blacks and Hispanics in doctoral science and engineering degree-taking has increased very slowly in the past 10 years, despite several programs dedicated to minority students. (See table 3-9 for the proportion of Ph.D.s earned in science and engineering fields by U.S. minorities in 1987.)

Although the same proportion of minority as white Ph.D. recipients received their primary student support from stipends, Blacks are more likely than whites to use loans, and less likely to hold RAs.[59] Some Federal programs include:

- The Graduate Professional Opportunities Program of the Department of Education (now known as Javits Fellowships) which supports about 800 minority students in natural sciences, engineering, and law.
- NSF Minority Graduate Fellowships.
- NIH/National Institute of General Medical Sciences (NIGMS) Minority Biomedical Research Support Program (initially called the Minority Biomedical Support program), started in 1972 and closely affiliated with the NIH Minority Access to Research Careers (MARC) program.
- NIH/NIGMS MARC predoctoral training program. (MARC also includes programs for honors undergraduate research training, faculty fellowships, and visiting scientists.)
- Special programs for Indian education administered by the Bureau of Indian Affairs and the Department of Education's Indian Education Programs, although these do not focus on science and engineering per se.

Foreign Graduate Students

Foreign students are increasingly visible and important in American graduate programs in science and engineering. The United States benefits from this flow of

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[59] Michael Nettles, *Financial Aid and Minority Participation in Graduate Education*, A Research Report of the Minority Graduate Education Project (Princeton, NJ: Educational Testing Service, 1987), p. 5.

Table 3-9. — U.S. Science/Engineering Ph.D.s, by Race/Ethnicity and Field, 1987

	U.S. Minorities as percent of U.S. Ph.D.s		
	Blacks	Hispanics	Asians
All Science/engineering	2.1 (n=335)	2.3 (n=359)	6.0 (n=946)
Engineering	1.3	1.8	17.1
Physical sciences	1.0	2.3	6.8
Physics	0.9[a]	1.6[b]	4.6
Chemistry	0.9[b]	3.0	7.4
Environmental	0.4[a]	1.1[a]	4.0
Mathematics	2.8	2.8	10.4
Computer science	0.7[a]	1.5[a]	9.5
Life sciences	2.4	2.0	5.6
Biological	1.9	2.0	5.4
Agricultural	2.3	2.4	6.3
Health	4.9	1.7[b]	5.5
Social sciences	3.7	3.5	3.1
Psychology	3.3	3.5	1.7
Economics	2.9[b]	2.7[b]	8.7
U.S. minorities as percent of all science/engineering Ph.D.s, including foreign citizens[c]	1.7	1.8	4.7

[a] $n<15$

[b] $n<10$

[c] Non-U.S. citizens on temporary visas. Included as U.S. citizens are non-U.S. citizens on permanent visas (6% of U.S. science/engineering Ph.D.s) and those of unknown citizenship (7% of U.S. science/engineering Ph.D.s). Non-U.S. citizens on permanent visas almost always stay in the United States.

SOURCE: National Research Council, Survey of Earned Doctorates, unpublished 1987 data.

talent; many of these students stay, acquire permanent visas, and add to the scientific vitality of the Nation. Less than one-half of foreign science and engineering Ph.D. recipients remain in this country for at least a few years; the percentage is slightly higher, about 60 percent, for engineering and computer science. About 80 percent of the increase in foreign-origin scientists and engineers in the U.S. work force between 1972 and 1982 was due to students who stayed on after earning the doctorate.[60]

The overall share of science and engineering Ph.D.s awarded to foreign students is increasing, 22 percent in 1987.[61] Foreign graduate students concentrate in high-growth, high-payoff fields, and in technical areas rather than humanities and social sciences: one-half are in engineering and 25 percent in the sciences. They account for 3 percent of U.S. higher education enrollment overall, 5 percent of B.S. degrees in science and engineering, and 25 percent of full-time science and engineering graduate students in Ph.D. institutions.

Foreign students go on to fill many faculty positions. Nearly one-half of young engineering faculty are foreign. Among those under age 36, the proportion of foreign nationals rose from 11 percent in 1975 to 47 percent in 1985 (see figure 3-11).[62]

Foreign students generally are ineligible for direct Federal support (fellowships and traineeships) and thus tend to rely on university TAs and RAs and support from home.[63] There also are limitations on having them as research assistants on defense-sponsored research grants. While foreign students are required by the Immigration and Naturalization Service to demonstrate that they will be funded for at least 1 year of study, once enrolled in graduate schools they can seek the same institutional fellowships and assistantships as Americans. Not surprisingly, foreign Ph.D. recipients are more likely than Americans initially to have support from their families or home countries, and to receive institutional support such as TAs and RAs.[64]

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[60] Michael G. Finn, Oak Ridge Associated Universities, "Foreign National Scientists and Engineers in the U.S. Labor Force, 1972-1982," June 1985.

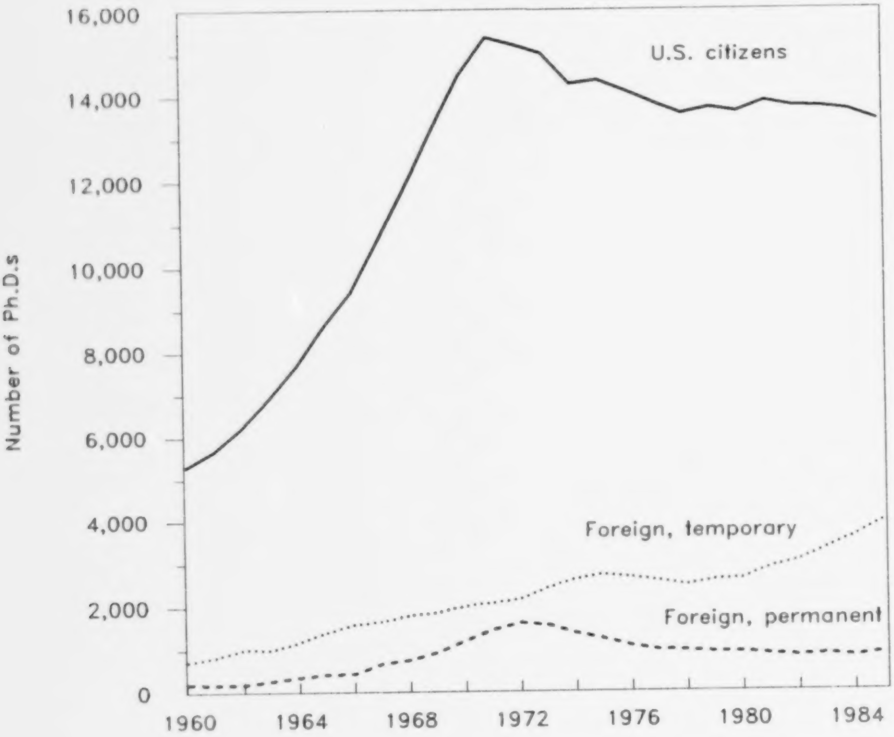
[61] The growth of foreign students in engineering is discussed further in ch. 4.

[62] National Research Council data, cited in *Manpower Comments*, July-August 1987, p. 27.

[63] Annual fellowship stipends range between $10,000 and $18,000 (paid directly to the student) and, in addition, usually cover tuition and fees (paid to the university, usually about $6,000). One wonders whether the growth of foreign students in U.S. graduate schools has expanded the use of research assistantships (for which all students are eligible), or vice versa. Christopher Hill, Congressional Research Service, personal communication, November 1988.

[64] National Science Foundation, *Foreign Citizens in U.S. Science and Engineering:*

Figure 3-11.-Science/Engineering Ph.D. Awards by Visa Status, 1960-85



NOTE: U.S. citizens include unknown citizenship.

SOURCE: National Science Foundation, Foreign Citizens in U.S. Science and Engineering: History, Status, and Outlook, NSF 86-305 revised (Washington, DC: 1986), p. 91.

Luring student talent has overtaken mid-career immigration as the way the United States acquires qualified foreign scientists and engineers. Admissions of scientists and engineers as permanent immigrants have been between 7,000 and 13,000 a year (less than 2 percent of all immigrants), with fluctuations in part reflecting Federal immigration quotas tied to U.S. labor market conditions. By comparison, foreign nonimmigrant enrollment in higher education is 344,000, in science and engineering about 166,000, and in science and engineering graduate study about 75,000. In addition, another few thousand scientists and engineers enter on temporary and exchange visitor visas. Many graduating foreign students enter the work force, usually exchanging their student visas for other temporary visas.[65] In 1985, 21,000 students (about 8 percent of that year's entry) and 8,000 temporary workers (11 percent) were adjusted to permanent residence.[66]

Visa, naturalization, and employment policies affect the entry of foreign scientists and engineers into the work force. To attract and rebuild a base of U.S. citizens in science and engineering, most Federal student support programs require U.S. citizenship (usually a permanent visa is sufficient). There have always been restrictions, for national security reasons, on DoD and DOE support. Restrictions are most likely in fields of obvious and pressing importance to national military or economic security and in fields in which the concentrations of foreign students are highest. These two areas tend to be one and the same. Another bone of contention is that perhaps 10 times as many foreign students are trained in the United States as U.S. students are trained in other countries. But foreign students are not an economic drain on institutions or the U.S. economy.[67]

Immigration policies have affected the numbers and the national origins of students in science and engineering. Immigration quotas do not apply to entry on temporary visas, including student visas. Such temporary entry is generally unrestricted. Entry through the student route, switching from temporary student visa to temporary worker status and then immigration, is the dominant route of entry for scientists and engineers.[68] The

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History, Status, and Outlook, Special Report NSF 86-305 revised (Washington, DC: 1987), pp. 29, 105.

[65] Immigration and Naturalization Service, *Statistical Abstract 1987* (Washington, DC: 1987) p. 12.

[66] Immigration and Naturalization Service estimates.

[67] Elinor G. Barber (ed.), *Foreign Student Flows*, Report on a Conference, Apr. 13-15, 1984, IIE Research Report No. 7 (New York, NY: Institute for International Education, 1985), p. 12.

[68] Office of Technology Assessment, op. cit., footnote 30, pp. 63-65.

student route has become more important since changes in immigration policy made it more difficult for workers to obtain a visa unless they were already employed by a U.S. firm.

Economic and political conditions in the countries of origin dominate foreign student flows. A sevenfold increase in students from the 13 OPEC countries in the 1970s was responsible for one-half of the total increase; in the late-1970s and early-1980s, non-OPEC countries increased emigration on student visas. Ten countries contribute nearly one-half of the foreign students studying in the United States. Because of this concentration, foreign enrollments are sensitive to changes in host country policies.

Continued high inflow of foreign students could help keep academic demand for faculty high through the demographic trough, until the expected upswing in faculty demand in the mid-1990s. They may also ease fluctuating enrollments in particular fields, such as petroleum engineering, although generally they and U.S. students gravitate to the same fields.

Institutional Support of the Infrastructure for Graduate Education

A high-quality infrastructure — equipment, facilities, and libraries — is vital to high-quality graduate training. Institutional support is one pillar of the foundation of the Nation's capability for graduate education and scientific research (see box 3-E). Since the late-1970s there has been increasing concern within the academic community over the deterioration of equipment and facilities. A 1987 Congressional Research Service report summarized the academic consensus: ". . . current conditions of research facilities may have serious implications for the quality of future scientists and engineers produced by the Nation's universities."[69]

Most concern over deteriorating infrastructure centers on research capability; it is important also to ensure that policies attend to training capability. Some argue that obsolescent facilities and equipment lead to teaching of outmoded methodologies.[70]

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[69] U.S. Congress, Congressional Research Service, *Bricks and Mortar: A Summary and Analysis of Proposals to Meet Research Facilities Needs on College Campuses*, a report prepared for the Subcommittee on Science, Research and Technology, House Committee on Science, Space, and Technology, (Washington, DC: U.S. Government Printing Office, September 1987), p. 23.

[70] Ibid., pp. 157-158; and U.S. Congress, Office of Technology Assessment, "Scientific Equipment for Undergraduates: Is It Adequate?" Staff Paper, September 1986.

Universities that lack state-of-the-art equipment and facilities report difficulty attracting and keeping the best graduate students and faculty.[71]

Spending on equipment and facilities is about 15 percent of academic science and engineering expenditures, with facilities taking the major share. This rate is lower than it was in the mid-1960s (when it peaked at about 20 percent), but has been increasing slowly from a low of about 9 percent in 1970, in response to widely voiced concerns. Most infrastructure funds come from non-Federal sources (see figure 3-12). Donations from individuals, foundations, and industry have been fostered by Federal tax policy. The Federal Government supports about 65 percent of equipment expenditures; the Federal share for facilities is now below 10 percent and is declining.[72] However, Federal support has been more stable than other sources. Private universities have been particularly dependent on Federal funds and private contributions; public universities benefit from State support. All universities also rely heavily on issuing tax-exempt bonds.

Federal institutional development programs were stimulated by rapid post-Sputnik and baby-boom growth in graduate education and research. Concern over capacity drove expansion of university infrastructure. At the peak of Federal programs in 1965, direct Federal contributions supported about one-third of university spending on all types of science and engineering facilities, and one-half of spending on research facilities. Federal programs declined 85 percent (in real terms) between 1965 and 1984.

Special institutional support should be distinguished from another major vehicle of Federal support for university infrastructure, namely indirect costs or overhead — the light bulbs, heating and air conditioning, libraries, copy machines, sewer hookups, and, of course, support staff, which are necessary to all departments. Support for overhead is built into most research and training grants, and is now 25 to 30 percent of R&D support. Infrastructure — building operation and maintenance, building depreciation, and libraries — is about 42 percent of overhead.[73] In 1986, the Federal Government spent

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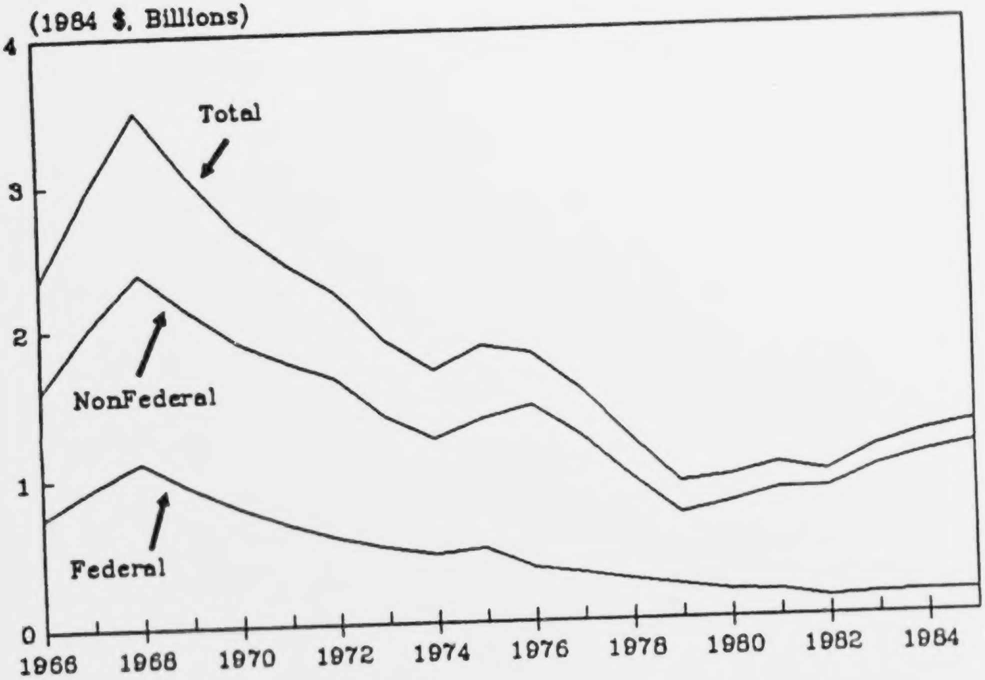
[71] Association of American Universities, *The Nation's Deteriorating University Research Facilities* (Washington, DC: July 1981), p. 11.

[72] National Science Foundation, "Academic Expenditures for Science and Engineering: Past, Present, Future," PRA Working Draft, April 1988, p. 6.

[73] National Science Foundation, *Future Costs of Academic Science/Engineering* (Washington, DC: April 1988). Based on a survey of top research universities, these estimates should be reasonably representative. Administrative costs are the largest and fastest rising component, over one-half of overhead. Student services are about 1 percent.

Figure 3-12.–Academic Science/Engineering Facilities Expenditures, by Source of Funds



SOURCE: National Science Foundation, Academic Expenditures for Science and Engineering: Past, Present, Future, Working Draft (Washington, DC: April 1988), p. 37.

about $350 to $400 million for equipment. In addition, smaller equipment and supplies are funded through regular research grants.

There is disagreement over how best to provide infrastructure support and the extent of the burden the Federal Government should shoulder.[74] Should the role of the Federal Government be simply to award research and training money, on a negotiated overhead rate, and let universities apportion that money among immediate operating needs of students, supplies, and faculty, and longer-term capital needs for chromatographs, computers, and laboratories? Or should the Federal Government take a more substantial role by directly funding equipment, facilities, and other institutional underpinnings?

As growth slowed, special institutional development was curtailed, leaving a base of Federal institutional support, primarily through overhead on research and training grants. This baseline has usually favored the best. In times of slow or no growth in education and research, R&D and training programs have usually concentrated in a small number of well-funded, well-equipped departments, with awards based on quality, efficiency, and the importance of a "critical mass" of people and research projects (see table 3-10). Equipment and facilities are concentrated in the top research universities (table 3-11).

However, facilities and large equipment cannot be funded by either small individual investigator awards or by indirect cost recovery. The large capital outlays needed for construction, major renovation, and large equipment demand big chunks of money. NSF estimates that $1 to $3 billion in equipment and $1.5 billion for facilities are urgently needed to compensate for underfunding in the past.[75]

Equipment and facility needs varies greatly by field and research problem. Manufacturing engineering, for instance, may rely on automated equipment costing

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74. See Congressional Research Service, op. cit., footnote 69. The history of Federal programs for facilities funding is discussed in ch. 4 of the Congressional Research Service report; impacts on education are summarized on pp. 151-160; policy options are discussed in chs. 5 and 7. The report reviews and integrates studies by the Association of American Universities, the National Science Foundation, the General Accounting Office, and others. See also, Stephen J. Fitzsimmons et al., *The Capacity of American Colleges and Universities to Train Science and Engineering Talent: A Survey of Universities, Scientists, Foundations, and the Private Sector*, a report to the National Science Foundation Division of Policy Research and Analysis (Cambridge, MA: Abt Associates, Inc., Jan. 15, 1985), pp. 24-26, 65-69.

75. National Science Foundation, op. cit., footnote 72, pp. ii-iii.

Table 3-10. — University R&D Support and Ph.D. Production, 1986

	Univ. (ranked by Fed. R&D $)	Number (& rank) 1986 NSE Ph.D.s		Fed. acad. S/E support, 1986	Federal f/t support, 1986	
1.	Johns Hopkins	141	(41)	$ 457,525	10,075	(2)
2.	MIT	436	(2)	207,867	7,260	(7)
3.	Stanford	392	(4)	195,454	9,866	(3)
4.	U. of Washington	246	(13)	157,154	7,745	(5)
5.	UCSD	140	(44)	140,878	5,147	(15)
6.	Columbia	211	(20)	142,430	5,575	(13)
7.	UCLA	281	(12)	133,150	5,255	(14)
8.	U. Wisc-Madison	406	(3)	138,827	4,793	(17)
9.	Cornell	360	(7)	149,599	4,425	(18)
10.	Yale	150	(36)	123,849	9,143	(4)
11.	U. Michigan	340	(8)	120,168	5,950	(12)
12.	Harvard	234	(14)	125,127	11,919	(1)
13.	UCSF	46	(112)	113,828	7,525	(6)
14.	U. Pennsylvania	181	(26)	112,305	6,926	(10)
15.	U. Minnesota	371	(6)	114,473	3,746	(21)
16.	UC-Berkeley	557	(1)	104,958	6,996	(9)
17.	U. Ill-Urbana	379	(5)	103,091	1,509	(40)
18.	Penn State	230	(16)	99,665	1,009	(51)
19.	USC	176	(28)	80,145	1,518	(38)
20.	U. Texas-Austin	296	(10)	76,288	935	(52)

NOTE: There is about a 70 percent overlap; 14 of the top 20 Federal R&D recipients are in the top 20 natural science and engineering (NSE) Ph.D. producers. The other 6 institutions are listed below.

Other High NSE Ph.D.-Producers

Purdue	316	(9)	57,424	871	(57)
Ohio State	294	(11)	78,746	715	(65)
Michigan State	233	(15)	59,788	653	(69)
UC-Davis	230	(17)	45,798	1,520	(37)
Texas A & M	226	(18)	53,341	394	(98)
U. Maryland	212	(19)	59,098	523	(84)

SOURCE: National Science Foundation, *Federal Support ot Universities, Colleges, and Selected Nonprofit Institutions, Fiscal Year: 1986*, NSF 87-318 (Washington, DC: 1987), pp. 19-24; and National Science Foundation, *Science and Engineering Doctorates: 1960-86*, NSF 88-309 (Washington, DC: 1988), pp. 153-156.

Table 3-11. — Distribution of Graduate Student Primary Support and Federal R&D Among Top 100 Research Universities, 1986

(in percent)

	Full-time grad students	All research assistantships	All fellows	All trainees	All teaching assistantships	Self/ other[a]	Federal academic
Top 10[b]	12	15	15	17	8	9	26
Top 20	25	30	32	34	20	22	40
Top 50	46	52	56	56	40	37	75
Top 100	67						86

[a] Overall, self-support is about 77 percent of self/other support.

[b] Universities ranked in order of receipt of Federal academic R&D funds (out of 325 total doctorate-granting institutions).

SOURCE: National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), pp. 329-342; and *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions, Fiscal Year: 1986*, NSF 87-318 (Washington, DC: 1987), pp. 21-22.

hundreds of thousands of dollars. Mathematics research may demand multimillion dollar supercomputers or simply chalk and blackboard. The Federal Government cannot underwrite these costs, but it can recognize their magnitude and act as a kind of investment counselor.

Postdoctoral Appointments

The postdoctoral appointment, as noted earlier, is a holding tank for talented Ph.D.s who cannot land the "right" job. Thus, it is seen by many as both a means of augmenting one's skills and as a proving ground, particularly in the life sciences. Postgraduates establish credentials as independent researchers, carving out their own research programs as distinct from those of their mentors and demonstrating the productivity that will earn them permanent faculty positions. Postdoctoral students are much more likely than graduate students to be supported by the Federal Government. Two-thirds are in the life sciences; 70 percent of life sciences Ph.D.s take postdoctoral appointments, compared with about one-half of Ph.D.s in the physical sciences.

Urgent national needs can be met most quickly by shifting postdoctoral support.[76] The number of postdoctoral appointments have increased steadily, from 6,100 to over 24,000 between 1965 and 1986. Approximately three-quarters of these appointments are supported by Federal funds, a proportion that has remained stable since data were first collected in the early-1970s (see figure 3-13). Unlike support of graduate students, Federal postdoctoral support has remained stable, increasing in the number of awards as the number of candidates increase.

With the current scarcity of science faculty positions in universities, more recent Ph.D.s are entering nontraditional academic jobs as nonfaculty research staff (see box 3-F). There are about 5,000 nonfaculty research staff, compared to over 20,000 postdoctoral students, in universities, according to NSF. Compared to postdoctoral researchers, nonfaculty research staff are less likely to be in life sciences, and more likely to be in engineering and social sciences.

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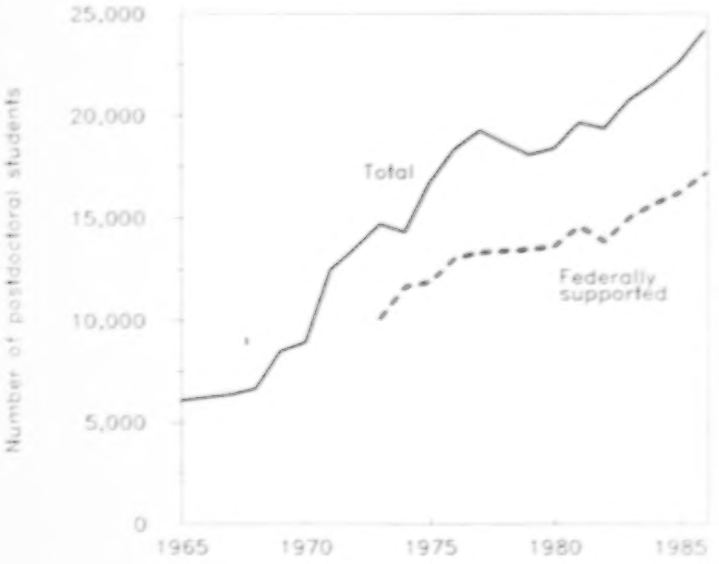
[76] William Zumeta, "Anatomy of the Boom in Postdoctoral Appointments During the 1970s: Troubling Implications for Quality Science?" *Science, Technology, & Human Values*, vol. 9, No. 2, spring 1984, pp. 23-37. For example, the mobilization of biomedical specialists to accelerate basic research on AIDS should soon be apparent sheerly in the size of the postdoctoral pool of intra- and extramural scientists supported by the National Institutes of Health.

Figure 3-13.—Science and Engineering Postdoctoral Students in Degree-Granting Institutions, Total and Federally Supported, 1965–86



NOTE: 1978 data are interpolated.

SOURCE: Betty M. Vetter and Henry Hertzfeld, "Federal Funding of Science and Engineering Education: Effect on Output of Scientists and Engineers, 1945–1985," OTA contractor report, 1987, based on National Science Foundation data.

Field Differences: The Pluralism of Ph.D.s

While this chapter has focused on broad field differences, disaggregated analysis is necessary to assess the quantity and quality of new Ph.D.s. However, the smaller and more specialized the scientific field being studied, the less predictable are changes in the factors that affect graduate enrollments and doctoral degrees awarded. Small changes in the total supply of scientists and engineers can mask significant adjustments within and among fields.[77]

For example, research physicists and astronomers depend mainly on Federal research funds awarded to universities and national laboratories. In chemistry, university research is overshadowed by industrial R&D, which employs large numbers of R&D chemists at all degree levels, particularly Ph.D.s. Environmental sciences (earth, atmospheric, and ocean sciences) is a small field, with a core of geologists dependent on the health of the oil and mining industries and a collection of interdisciplinary researchers responding to environmental R&D priorities.

Within fields, shortages and surpluses occur in specific research specialties. Thus, there are now surpluses of new graduates in particle physics and petroleum geology, and at the same time shortages in optical physics, condensed matter physics, and geochemistry. In some instances, there are continuing mismatches between supply and demand, as in the continuing overproduction of particle physicists and theoretical physicists relative to research opportunities. Many earth scientists are employed in the petroleum and mining industries, which are buffeted by business cycles and resource policies. Mathematics is a key field of research that depends largely on academic employment, not only for research but for service teaching.

The life sciences are big and diverse, including the biological sciences, the health and medical sciences, and the agricultural sciences. Sophisticated new instrumentation and the accelerating pace of discovery have blurred the boundaries between these fields. The Federal Government has long had a substantial stake in research and training in these fields, because of the high national priority vested in health-related basic and clinical research. Agriculture has been the longest standing federally supported research and training area, but funding is much lower than in the health and biological sciences.

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77. Office of Technology Assessment, op. cit., footnote 57. For an example of subfield specialization in physics, see Roman Czujko et al., *Society Membership Profile: The Pattern of Subfield Associations* (New York, NY: American Institute of Physics, Manpower Statistics Division, 1986), pp. 9-16.

Much of the growth and relative stability in the employment of agricultural scientists is in the extensive nationwide network of U.S. Department of Agriculture research facilities and the State agricultural experiment stations associated with the land-grant universities.

Social sciences are different from natural science and engineering. Psychology is the largest field in the social and behavioral sciences, accounting for one-half of Ph.D.s. Over one-half of recent Ph.D.s in psychology have been awarded in clinical subfields, and new Ph.D.s increasingly enter private or public clinical practice instead of pursuing traditional academic careers.[78]

Engineering Doctorate Education

Engineering doctorate education differs from science doctorate education in several ways. Generally, graduate education in engineering is dominated by master's students oriented to the industrial labor market (see chapter 4). For those who complete doctorates, attractive industry jobs and salaries also lure new Ph.D.s away from faculty jobs. Unemployment among Ph.D. engineers is nil.

Because of this and the great interest of foreign students in studying engineering, less than one-half of engineering graduate students are American. The problem is accentuated by the strong demand of defense-related employers for American engineers. The end result is that there has been a continuing, and at some times critical, shortage of young American Ph.D.s interested in faculty positions (the primary source of new faculty).

What can be done? Some universities have responded by creating a separate, higher pay scale for faculty in areas where there is strong competition with industry, such as engineering and business. This has worked to some extent. Many have proposed attracting more graduate students by increasing stipends, using as a rule of thumb that stipends should be at least one-half starting salaries for college graduates. (Some faculty salaries may begin to pale in comparison.)

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[78] Georgine M. Pion and Mark W. Lipsey, "Psychology and Society: The Challenge of Change," *American Psychologist*, vol. 39, No. 7, July 1984, pp. 739-754; and Ann Howard et al., American Psychological Association, "The Changing Face of American Psychology: A Report From the Committee on Employment and Human Resources," unpublished manuscript, 1986.

In 1986, a time when faculty shortages were still widespread/high but easing, engineering departments were asked to identify the main factors limiting Ph.D. production in engineering (see table 3-12).[79] The one response cited by nearly all respondents was "insufficient funding for graduate student support." Nearly 40 percent of department chairs ranked this as the most important factor.

THE FUTURE OF THE UNIVERSITY: A STEADY STATE ERA?

Graduate education is embedded in the research community and the research university infrastructure. External trends in the global economy, national defense, and competitiveness are changing the Nation's posture toward R&D and the missions of the research universities. In turn, this is affecting graduate education. The changing environment of the research university not only affects supply and demand, but also has reduced the appeal of a university research and teaching career for young scientists or engineers.

Despite the Federal Government's vigorous commitment to basic research, support for defense projects and industrial R&D has grown at the research universities. Economic pressures are forging new research links between university and industry.[80] Many States have devised programs to leverage universities as pivotal actors in research-fueled regional development. And expansion of students, faculty, and research has plateaued.

University research and graduate training can be characterized as a transition to a steady state of Federal funding, increasing competition for resources, and restructuring in the search for new sources of support and new missions. Grant competition and pressures for accountability are increasing the administrative burden on scientists in universities while diverting them from research. The upshot is that the attractiveness of an academic research career has waned from its peak of two decades ago.[81]

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[79] Paul Doigan and Mack Gilkeson, "ASEE Survey of Engineering Faculty & Graduate Students: Fall 1985," *Engineering Education*, October 1986, pp. 54-55. The survey of 180 major engineering departments was one in a series of regular surveys conducted by the American Society for Engineering Education.

[80] Dorothy Nelkin and Richard Nelson, "Commentary: University-Industry Alliances," *Science, Technology, & Human Values*, vol. 12, winter 1987, pp. 65-74. Such alliances, however, have a long history. See Roger L. Geiger, "Milking the Sacred Cow: Research and the Quest for Useful Knowledge in the American University Since 1920," *Science, Technology, & Human Values*, vol. 13, summer & autumn 1988, pp. 332-348.

[81] John Ziman, *Science in a 'Steady State': The Research System in Transition*

Table 3-12. — Factors Limiting Engineering Ph.D. Production: A Survey of Engineering Departments, 1986

	Percent of faculty citing that factor as 1st or 2nd most important	
	1st	2nd
Insufficient funding for graduate student support	38	35
Insufficient number of qualified students	33	16
Limitation on size of graduate stipends	14	28
Insufficient facilities and space	14	16
Insufficient qualified faculty	0	4
Other	1	1

SOURCE: American Society for Engineering Education Survey of Engineering Faculty and Graduate Students, fall 1985, reported in *Engineering Education*, October 1986, p. 55.

Writing in 1977 about the physical and intellectual infrastructure of the research university, Smith and Karlesky observed that:

> . . . young investigators must work in a far less encouraging research environment than the expansive one enjoyed by their counterparts a decade ago. Flexible funds are not so readily available; in the physical sciences fewer graduate students are around to assist in research; universities are less able to provide start-up funds; and the competition for external grants has intensified. More demanding tenure standards have created obvious pressures of their own. It is unquestionably much more difficult for the young to establish themselves now than it was 10 years ago, but this is a result of the steady state environment for research. . . .[82]

In 1968 Harvey Brooks warned of the implications of the impending slowdown in exponentially growing Federal academic support:

> If academic research budgets continue to level off, grave questions of policy will be posed. The vigor of a scientific field seems to depend on a continuing injection of new investigators with fresh ideas and on sufficient funds to exploit new ideas and replace outmoded equipment. . . . In the absence of new funding, it will be necessary to invent new mechanisms of funding which will permit greater concentration and specialization of effort. . . . To spread the same funds more and more thinly over a growing number of investigators, institutions, and students would be a prescription for the slow strangulation of science in the United States.[83]

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82. Bruce L.R. Smith and Joseph J. Karlesky, *The State of Academic Science: The Universities in the Nation's Research Effort* (New York, NY: Change Magazine Press, 1977), p. 183. Also see John Ziman's review of this book, "Bounded Science," *Minerva*, vol. 16, 1978. pp. 327-339. With the benefit of another decade of hindsight, one might observe that the thunderous Federal support of universities in the 1960s was an aberration. "Current university practices, orientation, and leadership were all formed during the 60s. The current challenge is to put academic science and engineering back on a realistic slow growth path." Christopher Hill, Congressional Research Service, personal communication, November 1988.

83. Harvey Brooks, "The Future Growth of Academic Research: Criteria and Needs," *Science Policy and the University*, Harold Orlans (ed.) (Washington, DC: Brookings Institution, 1968), pp. 75-76.

Universities are searching for ways to maintain the viability of the research enterprise.[84] Brooks' prescience reveals in two ways the dilemma of science in the steady state: the growing uncertainties and fluctuations of Federal patronage that created a research system it can no longer sustain, and a selective infusion of industrial and State patronage and congressional earmarking on campus that, in the absence of a system for establishing research priorities, fortifies certain research agendas while starving others.[85]

No matter what the research objectives for the 1990s are, they will not be attainable without a qualified human resource base for doing science and technology. The difficulty of the Federal Government and institutions of higher education in ensuring long-term research support creates instabilities in the supply of science and engineering Ph.D.s.[86] David Hamburg has observed that:

> . . . the Federal Government was a major actor in the creation of the "bulge" in academic R&D in the 1960s whose effects persist to this day. Federal

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[84] Don I. Phillips and Benjamin S.P. Shen (eds.), *Research in the Age of the Steady-State University*, American Association for the Advancement of Science Selected Symposium 60 (Boulder, CO: Westview Press, 1982).

[85] Some observers bemoan this as a problem of selecting between big (superconducting supercollider, space station, human genome mapping) and little science; others see the problem as defense v. civilian R&D; and still others warn of "fashionable" research that is either profitable or vital for U.S. economic competitiveness (biotechnology, superconductivity, advanced materials). A framework for weighing alternatives, making choices, and plugging them into the political process has been lacking. Lacking as well, however, is the discretionary budget for supporting all intellectually and economically promising R&D. For recent attempts to construct a framework, see National Academy of Sciences, *Federal Science and Technology Budget Priorities: New Perspectives and Procedures* (Washington, DC: National Academy Press, 1988); Frank H.T. Rhodes, "A System to Set Science Priorities," *Technology Review*, November/December 1988, pp. 21-22, 25; and John A. Dutton and Lawson Crowe, "Setting Priorities Among Scientific Initiatives," *American Scientist*, vol. 76, November-December 1988, pp. 599-603. For an approach that favors the proclivities of a sitting president (and a strong science advisor), see Edwin Diamond and Norman Sandler, "Science, Technology, and the Next President," *Issues in Science & Technology*, vol. 4, fall 1988, pp. 56-61.

[86] Lewis C. Solmon and William Zumeta, "U.S. Science Manpower and R&D Capacity: New Problems on the Horizon," *Policy Controversies in Higher Education*, Samuel K. Gove and Thomas M. Stauffer (eds.) (New York, NY: Greenwood Press, 1986), p. 208. For a European perspective, see R.J. Cavanagh, *Workshop on Assessing the Availability and Need for Research Manpower: Activities in OECD Countries — Preliminary Report* (Paris, France: Organisation for Economic Cooperation and Development, Directorate for Science, Technology and Industry, Sept. 2, 1988).

> policy can and does have major shaping effects, positive and negative. . . . It seems reasonable that since the Federal Government has been a major beneficiary of the build-up it should also share in attempting to ameliorate the negative effects of the build-up distortions.[87]

In this transition era, graduate institutions that sustain the dual missions of graduate teaching and research must confront numerous questions, or become beleaguered by unyielding demands and insufficient resources.[88] How does the financing of research affect the environment in which the next generation of researchers is being trained? How do the pressures and perquisites of sponsors alter the relations between faculty and students, between research and teaching, between career expectations and opportunities? If faculty roles now include entrepreneurship, does this imply that apprentice-researchers to these faculty-mentors tend to be oriented to nonacademic employment?

There is currently great pressure for industry collaborative and center-based work at universities. There is also a great deal of concern about such relationships from those who fear that education would wither under the pressures of capitalism and that students would be exploited for financial gain.[89]

The pressure for increased collaboration emanates from government leaders, big industry, NSF, and the management of large research universities who feel that university and industry competencies are diverging, given the "evidence" of problems with U.S. manufacturing, the growing prowess of Japan, and the perceived need for researchers and curriculum to be more "relevant." A more subtle pressure derives from suspicions — inside universities and out — that the traditional disciplines are no longer fertile and should give way to interdisciplinary R&D and more "real-world" work.

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87. Hamburg, op. cit., footnote 3, pp. 29-30.

88. "[W]e are creating two faculties: one devoted to bringing in research grants and publishing as many papers as possible, and the other relegated to handling the teaching load. . . . Many professors will retire in the next decade or so. And when this happens, replacements of quality and dedication will be tough to find as their mission becomes even less prestigious." Douglas E. Kelly, "We are Eroding the Vital Link Between Academic Research and Education," *The Scientist*, Oct. 17, 1988, pp. 9-10.

89. For example, Martin Kenney, *Biotechnology: The University-Industrial Complex* (New Haven, CT: Yale University Press, 1986). Survey responses from graduate and postdoctoral students (who of necessity tend to minimize professional cognitive dissonance) suggest that this concern is overstated. See Michael E. Gluck et al., "University-Industry Relationships in the Life Sciences: Implications for Students and Post-Doctoral Fellows," *Research Policy*, vol. 16, 1987, pp. 327-336.

Little is as yet known about the educational impacts of large research centers and more pervasive university-industry collaborations. All accounts stress the educational function of centers, but few specifics are available. For example, the Semiconductor Research Corp. is developing a curriculum in microelectronics manufacturing for engineering students with Florida State University and Florida A&M University.[90] Given the uncertainty surrounding the impacts of collaborations, perhaps the best policy is to emphasize concern for education, and continued monitoring.

Some hoped-for benefits of closer industry-university contacts are:

- the ability of industry to find the best talent as soon as possible;
- more "relevant" and "real-world" education in those areas that need more relevant engineering (e.g., combustion);
- the ability for students to work in a multidisciplinary center that cuts across departments;
- the opportunity to work with people in teams (this must be something of a myth, because faculty-based work often has several investigators and, in any case, always contains some teamwork);
- a reduction in the government and university burden of support of students; and
- more undergraduate participation in research.

Some feared impacts are:

- the siphoning off of students who would continue on for the Ph.D.;
- the increased secrecy and "ownership" of information; and
- the arrival of the profit ethic on campus, changing the ethos of university education.

Evidence from historical and contemporary case studies, while not conclusive, suggests that specific fields and the research university as a whole cope well with new research missions (see boxes 3-G and 3-H).

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[90] Ralph K. Cavin III and D. Howard Phillips, "SRC: A Model of Industry-University Cooperation," *Engineering Education*, vol. 78, January 1988, p. 227.

The Future Supply of Ph.D.s

The future supply of Ph.D.s is a matter of quality as well as of numbers. Many fear that higher-paying occupations will attract more of the most talented students, as graduate study and academic careers, salaries, and lifestyle become relatively less attractive.[91] Assistant professorships at colleges and universities continue to provide the lowest salaries.[92]

The job market for Ph.D.s is unusual. While it responds to demand (in particular, national R&D funding) and to immediate research and training support, the supply is particularly sensitive to Federal policies.[93] As for quality, at the margins talent can be lured or discouraged to relieve shortages and surpluses. The well-documented elasticity at the baccalaureate level does not hold as readily at the doctoral level.[94]

The academic job market is not as attractive as it used to be, even in the post-golden age of the 1970s. Faculty-investigators weaned on "safe" Federal funding must seek new strategies to ensure continuity in their research programs and teams. Time-consuming and relentless competition for research funds coupled with uncertainty over future funding deter students from pursuing Ph.D.s, and then deter new Ph.D.s from seeking academic careers.[95] Well-funded, well-salaried, stable positions in well-equipped industry research laboratories appear more and more attractive. As more industry goes "high-tech," researchers are attracted by good equipment and working conditions, and the advantages of university life dwindle.[96]

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91. Solmon and Zumeta, op. cit., footnote 86, pp. 193-194.
92. Eleanor L. Babco, *Salaries of Scientists, Engineers and Technicians: A Summary of Salary Surveys*, 13th ed. (Washington, DC: Commission on Professionals in Science and Technology, 1987).
93. Allan M. Cartter, "Scientific Manpower for 1970-1985," *Science*, vol. 172, Apr. 9, 1971, p. 139.
94. Richard Freeman, "Supply and Salary Adjustments to the Changing Science Manpower Market: Physics, 1948-1973," *American Economic Review*, vol. 65, March 1975, pp. 27-39.
95. National Science Foundation, "Recent Doctorate Faculty More Actively Seeking Research Support," *Mosaic*, vol. 18, winter 1987/88, back page.
96. Hill offers an alternative "autonomy" hypothesis: In the "golden age," university faculty positions offered the greatest autonomy; in this new era of venture capital, a more lucrative (and risky) route to autonomy is the small, start-up high-technology firm. There, he says, "you'll find the 'lost faculty'." Christopher Hill, Congressional Research Service, personal communication, November 1988.

Universities are in a vulnerable position. Faculty retirements are expected to rise significantly in the 1990s. Foreign citizens are routinely recruited to faculty appointments in engineering and mathematics. So, too, are racial and ethnic minority Ph.D.s. But their numbers in the pipeline are still small, so academic departments compete for a scarce resource.[97] The current tenure glut that forced universities to create nontenure track positions will be relieved somewhat by faculty retirement.[98] Universities are avoiding swelling their permanent faculty ranks, mimicking a trend toward temporary and contract hiring in corporations. Instead of filling vacated positions with new full-time tenured and tenurable faculty, a dual-track ladder of temporary full- and part-time researchers and teachers may develop. This new set of positions would reflect employers' demand for an elastic academic work force, one that expands and contracts with the waxing and waning of Federal and industrial research priorities.

One way universities cope is by specializing and concentrating resources. Few research universities, 50 to 100 according to different criteria, have the resources to maintain a breadth of research programs across the spectrum of science and engineering fields. For 250 other Ph.D.-granting institutions to try to emulate the formula and success of the 100 would be challenging and costly. The Federal Government is the dominant source of revenue for research universities. There is a sense that, since R&D funding and good faculty are limited, improving one university must to some extent come at the expense of another (unless an infusion of industrial or other expenditures occurs). This tradeoff was perceived almost two decades ago:

> . . . it is urgently necessary for the Federal Government to identify a category of "national universities," perhaps 75 to 100 in number, and guarantee certain minimum support levels for graduate education, research, and student aid. If the task of identifying institutions is too difficult, or too

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[97] Shirley Vining Brown, *Increasing Minority Faculty: An Elusive Goal*, A Research Report of the Minority Graduate Education Project (Princeton, NJ: Educational Testing Service, 1988). The obvious long-term goal is to expand the resource; trading scarce talent — regardless of sex, race, ethnicity, or physical handicap — across sectors and fields will not satisfy the need. The "new demographics" make this painfully clear. See Office of Technology Assessment, op. cit., footnote 30, pp. 7-13; and *Manpower Comments*, October 1988, pp. 14-21.

[98] The "relief," according to some, will be profound and problematic. See Carol Boyd Leon, "Good-bye, Mr. Chips: Get Ready for a Shortage of College Professors," American Demographics, October 1988, pp. 332-35.

> politically explosive, then a workable alternative might be to select 50 to 75 departments from each of the major disciplines, with Federal support going only to the most eminent or promising fields of the study in any single institution. . . . [T]he failure to develop a more effective and rational system of support of graduate and professional education is likely to dangerously erode the greatest achievements of American higher education.[99]

The vast majority of scientists in a recent national survey disagreed with a policy of spreading cuts evenly across all universities.[100] Targeting the most Ph.D.-productive research universities for sustained support is the surest way of ensuring the flow of fresh talent into the research work force.[101]

One approach to creating academic posts and making academic life more appealing is the U.S. Presidential Young Investigator program, which bestows prestige and several years of generous funding upon young faculty. Several European nations, facing the same situation, have implemented similar programs (see box 3-1).

Lessons From the Golden Age

The energetic Federal build-up of graduate education in the golden age of the 1960s enhanced research, education, and the research work force, but left a legacy of overexpanded departments, and abruptly curtailed careers as young Ph.D.s and graduate students adjusted to the unanticipated and severe cutback in Federal support.

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[99] Cartter, op. cit., footnote 93, p. 139.

[100] Sigma Xi, *A New Agenda for Science* (New Haven, CT: 1987), pp. 22-24. Seventy percent disagreed with the statement: "During periods of retrenchment of Federal support of research a desirable policy is to distribute the cuts across the board on a flat percentage basis, thereby to spread the pain evenly." The survey was of Sigma Xi members — a selective, rather than representative, sample of U.S. university faculty. For an historical perspective, see David W. Breneman, *Graduate School Adjustments to the "New Depression" in Higher Education,* Technical Report No. 3 (Washington, DC: National Board on Graduate Education, February 1975), pp. 24-27, 30-35.

[101] Harvey Brooks, "The Research University: Doing Good, and Doing It Better," *Issues in Science and Technology*, vol. 4, winter 1988, pp. 49-55. A 5-year national Project for Research on Doctoral Education, in progress at the University of Rochester, is examining student financing methods, among other aspects of graduate education. The project is conducted under the auspices of the Association of Graduate Schools in the Association of American Universities and sponsored by the 46 participating institutions and grants from the Pew, Mellon and Lilly foundations. Findings of this project may inform the perspectives of the two camps and the higher education investment strategy of the Federal Government.

Snyder offers several lessons from this Federal build-up and its ramifications.[102] Many echo the themes of this chapter:

1. Federal policies should take into account market forces and their synergistic interaction with Federal programs; State, institutional, industry, and Federal R&D spending changes all increase education and research support.
2. It takes at least 4 and, on average, closer to 7 years to produce a Ph.D. Therefore, the effects of graduate education policies may not be evident for several years; in the 1960s, by the time a Ph.D. surplus became apparent, Ph.D. production was still increasing rapidly and there were still large numbers of unsuspecting graduate students in the pipeline. Earlier tapering off of support would have been better.
3. Heed demographic trends; in the 1960s, there was a demographically driven slowdown in undergraduate enrollments and a federally mandated acceleration of opportunities to acquire a higher education.
4. Supply and demand projections are easy to overinterpret and use improperly, but keep working at them.
5. Federal agencies should take the level of RAs into account in setting levels of fellowship and traineeship support.
6. If programs are supposed to provide long-term support for core institutions and core talent, ensure that those programs are long term and stable.
7. Carefully consider optimal roles for agencies in institutional, and research and student support. Coordinate programs. System upgrading and institutional development might be more appropriate for NSF, and maybe NIH, while more targeted, research-related programs seem best for the narrower mission agencies such as DOE and NASA.

The legacy of the golden age can be stated as: the science base is only as strong as the investment in people — first and foremost.

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[102] Snyder, op. cit., footnote 8, pp. 42-44.

Box 3-A. — Letters From Graduate Students

Lloyd Whitman, "Consider Graduate-Student Life,"
Physics Today, June 1986, p. 41

"The lack of concern for graduate-student life is manifested in many ways . . . an unmarried graduate student supported solely by a teaching or research assistantship lives frugally — after basic living expenses there is little money left over for repairs or extraordinary expenses. Students are particularly concerned that they lack the resources to cope with medical emergencies not fully covered by the nominal student health insurance. Most students agree that graduate school is not the place to start a family, especially considering the fiscal constraints imposed by current stipends. As it typically requires five or six years to complete a Ph.D., most students will be 26-30 years old before having the resources (not to mention the time) to start a family. The sacrifice is greatest for women, who will have spent their safest childbearing years in graduate school only to then have to choose between starting a family and embarking on a career. . . .

"What are the implications of these conditions? For instance, to what extent are qualified undergraduates discouraged from continuing with graduate work in physics? And for those who do continue, do the prospects of financial success influence the choice of research fields? At institutions where support for every student is not readily available, graduate students will be lured to fields that are currently well funded. Similarly, job prospects vary widely by subfield, creating an incentive for students to pursue the 'hot' new areas of research. This situation creates the danger that we will end up with a plethora of experts in currently active research areas, though these will not necessarily be of primary importance in years to come. . . . It may be that students under financial pressure will choose projects that will enable them to finish quickly rather than undertaking the projects for which they have the most enthusiasm. Lastly, one might consider whether the conditions of graduate life are conducive to the most productive graduate work. One hopes that students do not become so discouraged that their work is affected."

V. Chandrasekhar, "A Foreign Graduate Student Speaks Out," Engineering Education, April 1988, p. 666.

"First, some faculty are clearly looking for bargains in their research assistants (much like a coach in a "revenue sport" may look at an incoming student athlete). These faculty let the work aspect of the relationship (i.e., the fact that they pay about $350/month to their graduate assistants) completely corrupt the educational aspects. . . .

"The faculty members' desire to get the best bang for their buck results in their making inordinate demands in terms of the amount and quality of research work required, the rate of results, and the amount of support work expected . . . forgetting that a novice is at work, they may make demands for rapid results, as is done in industry when professionals do the work. They may ask graduate students to "live their thesis" — learn on their own and perform with little help the countless tasks necessary for typical engineering research work (computer programming, glassblowing, machine shop work, electroplating). . . .

"The result is that research assistants are forced to go into a crisis mode of living (similar to what happens in medical residencies). This is an important reason why not many qualified American students are interested in graduate study."

Box 3-B. — National Defense Education Act Trainees

From 1964 to 1973, the National Aeronautics and Space Administration (NASA) supported several thousand predoctoral trainees in a broad array of fields under Title IV of the National Defense Education Act (NDEA)[1] At that time, with Sputnik and the rapid space build-up, NASA's projected personnel needs were great and spurred direct NASA support of Ph.D. training. A 1961 report reflects the policy mentality of the times:

> NASA's needs in research appear certain to build up to a significant percentage of the total scientific reserach of the U.S. . . . The most direct way for NASA to assure itself of an adequate supply of Ph.D.s for its own position in research and administration, and for its contractors both in the universities and industry, would be to provide traineeships and fellowships for advanced students in the space-science fields and closely related sciences.[2]

So the NDEA traineeship program was born.

A study of the careers of NASA trainees who earned Ph.D.s is currently being conducted, looking at how trainees' careers developed and diverged for the 20-odd years following their traineeship.[3] Results from a pilot survey indicate that most trainees had been interested in science or engineering from an early age, and had chosen their field in high school or college. For these scientists the NDEA traineeships were more an additional and welcome source of money rather than a direct and immediate career lure. However, the NDEA program was part of a broad national endeavor in space, science, and higher education. Its impacts reached deep into the school system; many children were "turned on" to science by Sputnik and the widely-publicized NASA missions of the day.

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[1] The main purpose of the National Defense Education Act (NDEA) Title IV was ". . . to alleviate an existing and projected shortage of qualified college teachers." The National Aeronautics and Space Adminisration-supported fellows were but a portion of the NDEA program. The early history of NDEA is discussed in Clarence B. Lindquist, *NDEA Fellowships for College Teaching*, OE-55058 (Washington, DC: U.S. Department of Health, Education, and Welfare, 1971); and Laure M. Sharp, *Study of NDEA Title IV Fellowship Program, Phase I* (Washington, DC: Bureau of Social Science Research, Inc., March 1968).

[2] The National Aeronautics and Space Administration, *Working Group Report on NASA-University Relations* (Washington, DC: August 1961).

[3] The National Aeronautics and Space Administration (NASA) is supporting a survey of National Defense Education Act (NDEA) fellows, conducted out of the Space Policy Institute and Science, Technology, and Public Policy Program of the George Washington University, Washington, DC. About 4,000 NDEA/NASA-sponsored Ph.D. recipients will be surveyed in fall 1988. Most trainees were in the physical sciences or engineering. The survey is looking at influences on career choice, impacts of NDEA fellowships, and career patterns. See Jeffrey D. Rosendhal and Thomas Dietz, George Washington University, "The NASA Predoctoral Trainees of the 1960s: Where Are They Now and What Are They Doing?" unpublished interim report, June 1988.

Nearly all the Ph.D.s trained under the NDEA traineeships remained in science and engineering, and a surprisingly large fraction, over two-thirds, work in their Ph.D. field today. NDEA also supported students in broad areas of science only vaguely related to space. While it is impossible to compare the effects of NDEA training grants to other training grants or other forms of support, the preliminary conclusion of the study is that NDEA traineeships helped create a scientifically productive cadre of career scientists and engineers of great and lasting value to society (although not focused, as was intended, on space science).

NASA successfully spread training grants throughout all 50 States, and to institutions that had not been big recipients or Ph.D.-producers. Justification was that the top 20 were "saturated" in Ph.D. production. With this policy, the NDEA programs successfully broadened the university base for Ph.D. production.

Little long-term information is available on NDEA trainees who did not complete a Ph.D. One study of all 45,000 NDEA fellows showed that about 60 percent of the early fellows had achieved Ph.D.s by 1974.[4]

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[4] Lindsey R. Harmon, Commission on Human Resources, National Research Council, Career Achievements of NDEA (Title IV) Fellows of 1959-1973, Report to the U.S. Office of Education (Washington, DC: National Academy of Sciences, 1977), pp. 6-7, 10, 14-15. Fellows in the natural sciences and education had higher completion rates than social sciences and humanities fellows. In all fields, NDEA fellows completed their degree much faster than the average Ph.D., in some fields several years faster (based on elapsed time from receipt of B.S. to receipt of Ph.D.).

Box 3-C. — Women in Science and Engineering: Graduate Study and Financial Aid

Are women science or engineering students less likely to receive financial aid than men? The answer is yes. Several factors, however, cloud the situation.

First, women cluster in different fields of study than men; they are more likely to be in the social and biological sciences, and less likely to be in engineering and the physical sciences. Many forms of aid, particularly research assistantships, fellowships, and traineeships, are linked to field of study. As women tend to major in fields where less of such aid is available, they are less likely than men — averaging across all science and engineering fields — to receive financial aid.

So a better question is: Are women in, for example, physics or economics, less likely to receive aid than men in the same field? The answer is still yes. The reasons are even more subtle and complex, however, at this level of analysis. Many factors contribute to women getting less aid:

- **They are more likely to be attending graduate school part time, both overall and compared to men in the same field.** For some this may in part be due to family responsibilities, such as the need to care for young children or help support a husband.
- **They do not fare as well as men in receiving the more desireable forms of financial aid, such as fellowships, traineeships, and research assistantships (RAs).** Within any given field, women are less likely to receive RAs.
- **They are likely to be supporting themselves.** This continues a pattern observed in undergraduates: Women are less likely to receive grants, loans, or earnings from part-time jobs. The pattern continues when they enter the work force.[1]

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[1] The National Science Foundation 1986 New Entrants survey of recent college graduates shows that women employed full time in science or engineering earn 20 percent less than their male counterparts. Salary differentials vary by field; in engineering, men and women take home the same paycheck, while in the social sciences the salary differential is more than 20 percent. National Science Foundation, *Characteristics of Recent Science/Engineering Graduates: 1986*, NSF 87-321 (Washington, DC: 1987), p. 82.

A similar message comes from a different source. The U.S. Department of

Finally, while some financial aid is better than none, some forms are more valuable, in the sense of professional culture and career, than others:

> A research assistantship contributes to the quality of graduate education. It serves to integrate the student into the profession. It serves to teach him or her the sort of nontechnical elements of the profession. You learn how the grant mechanisms work. You become in the sciences, in a very important way, integrated into research groups, which no other form of support provides. So we see rather gradually, insidiously, differentiation taking place where women are expected to do a disproportionately higher share of undergraduate teaching, which takes them away from the company of their colleagues and faculty and puts them into a different environment with young students, while male students are working with faculty and regarded as colleagues. . . . They are likely to have more opportunities to publish before they actually finish their Ph.D.s. They are likely to have subsidized travel, attend meetings, have opportunities to be introduced to people in other institutions. . . .[2]

Education 1985 Recent College Graduate (RCG) Survey shows an overall 14 percent salary advantage for men employed full time in science and engineering about 1 year after graduation (3 percent in engineering, 16 percent in computer specialties, 23 percent in the natural sciences, and 43 percent in the social sciences). (For all professional occupations, RCG data show men to have a 35 percent salary advantage. Some of the salary difference may be due to the kinds of jobs women take, which is related to the jobs they are offered.) U.S. Department of Education, unpublished data.

[2] Lilli Hornig, Wellesley College, testimony, 1983, cited in Mary Moran, *Student Financial Aid and Women: Equity Dilemma?* (Washington, DC: ASHE-ERIC Higher Education Reports, 1986), pp. 27-28. Also see Fred M. Hechinger, "About Education: When Motherhood Interferes With the Training of Young Female Scientists," *New York Times*, Nov. 9, 1988, p. B11.

Box 3-D. — Women in Higher Education: Making an Institutional and Societal Commitment

The issues facing women studying and considering scientific careers derive mainly from the larger social and economic situation for women. Improving the participation of women in science and engineering requires addressing some of the larger issues about treatment of women in education, the workplace, and society at large.

Although women have made a great deal of progress, they still face many barriers. There is no one magic fix. Vigorous action on many fronts is required, supported by broad, sustained national commitment to equitable education and employment opportunities for all. A special report of the American Council on Education suggested that colleges and universities:[1]

- Seek strong commitment from the leadership of the institutions to understand and address the concerns of women students, faculty, staff, and administrators;
- Correct inequities in hiring, promotion, tenure, and salary of women faculty, administrators, and staff;
- Provide a supportive campus climate for women;
- Make a permanent institutional commitment to women's studies;
- Review all policies for effect on majority and minority women;
- Integrate impact studies into planning;
- Give specific attention to sexual harrassment;
- Prepare an annual status report;

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1. American Council on Education, *The New Agenda of Women for Higher Education: A Report of the ACE Commission on Women in Higher Education* (Washington, DC: n.d.).

- Initiate a campus values inventory;
- Develop an institution-wide concern for children and families;
- Appreciate the value of diversity;
- Make leadership development, and commitment to fostering women's leadership, joint priorities;
- Establish or reaffirm the commitment to a Commission on Women;
- Appoint a high-level person whose formal responsibilities include advocacy for women on campus; and
- Create a center for the exploration of community and personal relationships.

Box 3-E. — Institutional Support and Graduate Education

The rapid growth in Federal support of R&D and graduate education in the 1960s brought with it concern over the ability of U.S. universities to provide quality research and training during this expansion.[1] In response, Federal programs were established to improve and expand university infrastructure, apart from support of academic research and students. These institutional development programs had two broad aims: to improve the quality and capacity of well-established departments, with flexible funding for equipment, facilities, libraries, faculty, and other personnel; and to expand the number of high-quality departments by investing in "second-tier" institutions.

During this period, the National Science Foundation (NSF) funded three major institutional support and development programs, providing money for equipment, facilities, and faculty:

NSF Institutional Support Programs	**Total $ millions** (current dollars)	**No. Instit.**
Graduate Science Facilities (1960-1970)	$188	182
Science Development (1965-1972)	$233	104
Institutional Grants for Science (1961-1972)	$120	939
TOTAL	$541 (or $1,760 in 1987) constant dollars)	

According to one evaluation, these programs achieved their goals, with modest improvement of many departments and substantial, lasting improvement at a few institutions.[2]

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[1] Another significant portion of Federal support of educational institutions has been targeted to undergraduate education, to a large extent historically Black institutions and to a lesser extent predominantly undergraduate institutions. They are not discussed here, but they continue to figure significantly in Federal priorities. Federal institutional support of land-grant institutions, under the Morrill Acts of 1862 and 1890, by ensuring wide geographical distribution of resources, has also influenced science and engineering education.

[2] National Science Foundation, "Institutional Support Programs at the National Science Foundation, 1960-1972," PRA Issue Paper 84-26, May 21, 1984.

Graduate Science Facilities provided funds for facility renovation, repair, and construction at universities offering doctorate or master's degrees. Its 50 percent matching requirement successfully brought in State and private contributions for facilities. The goal of Institutional Grants for Science was to strengthen the research capability of existing high-quality institutions by providing discretionary funds, which universities spent on equipment, supplies, facilities, and personnel. Science Development was designed to increase the number of top-flight research universities. The Science Development program was the only one of these three NSF programs that was evaluated formally.

The NSF Science Development Program (SD) provided generous institutional development funds in the late 1960s to strong "second-tier" universities to nurture new centers of research excellence.[3] It was the first large-scale Federal venture into institutional development. The program began in 1965 and was terminated in 1972.

While the amount of SD money was large, it was still a small increment (15 to 20 percent) on top of a larger base of Federal funding to those institutions. The core of SD was University Science Development (USD), which awarded $177 million in flexible institutional grants to 31 public and private universities over 6 years (a little over $500 million in 1987 dollars). Typically four to five departments were built into each grant proposal. The grants ran for 3 years, with a potential 2-year supplement. NSF's decision process included site visits and peer review by university administration experts as well as scientists. Recipients were selected in part for geographic equity; USD money helped start Research Triangle Park in North Carolina. The average grant was about $6 million, spread over several years. Matching of State, private, and institutional funds was not mandated but was an important part of the program.

SD funds were described by recipients as catalytic, accelerating improvement and expansion and making possible ventures and facilities that otherwise would not have been possible. SD succeeded at its two major goals, lasting improvement in institutions and widened geographic distribution of funds. NSF was lauded for making good selections and for hands-off administration.

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[3] This summary is based on a National Science Foundation-commissioned evaluation of the Science Development program: David E. Drew, *Science Development: An Evaluation Study*, a technical report presented to the National Board on Graduate Education (Washington, DC: National Academy Press, June 1975); and National Board on Graduate Education, *Science Development, University Development, and the Federal Government*, Report Number Four (Washington, DC: National Academy of Sciences, June 1975).

The effect of USD was more apparent at public than at private institutions. Drew hypothesized that private institutions used the money to maintain all departments rather than expand in the financial retrenchment of the early 1970s. In terms of increasing faculty publication productivity and Ph.D. production, SD funds also had the greatest effect on less affluent institutions, where they represented a greater share of the budget.

Box 3-F. — Academic Marginals

In recent years the number of available faculty positions in universities has been far smaller than the number of new doctoral scientists.[1] Slowly growing faculty employment is not enough to take up the slack. Part of the surplus was once absorbed into postdoctoral fellowships that were extended until more suitable jobs became available. In the basic biomedical sciences, for example, the number of postdoctorals grew rapidly from 1974 through 1982, then leveled off, although the number of Ph.D.s awarded in those years grew very slightly.[2]

Many of these Ph.D.s have been directed into positions at the margin of the university. Variously termed "the unfaculty," "unequal peers," and "the nonfaculty,"[3] these scientists populate an academic "never-never land" made possible by and especially vulnerable to the availability of research support. Bearing such titles as "Assistant Research Anatomist," "Research Associate," or "Research Fellow," these scientists typically do not share the academic rights and privileges of their counterparts on the regular tenure-track faculty and typically earn lower salaries. In a few institutions, there is a well-defined career track outside the usual academic ranks for these people, so it is possible to attain the rank of full professor (or its equivalent), although usually without tenure.[4] Many are employed not by university departments, but by quasi-independent research units.

The number of marginal scientists has grown rapidly in recent years. According to National Research Council data, academic employment for doctoral scientists in nonfaculty positions (other than postdoctorates) grew at an annual rate of 7.8 percent between 1973 and 1979; in contrast, faculty employment grew 4.1 percent during that period.[5] Growth in nonfaculty positions has continued at an annual 7 percent rate into the 1980s, although it has slowed in 1986 (the last year for which there is published data).[6]

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[1] National Research Council, *Postdoctoral Appointments and Disappointments* (Washington, DC: National Academy Press, 1981); and Don Phillips and Benjamin Shen (eds.), *Research in the Age of the Steady-State University* (Boulder, CO: Westview, 1982).

[2] Institute of Medicine, *Personnel Needs and Training for Biomedical and Behavioral Research* (Washington, DC: National Academy Press, 1985), p. 56.

[3] Clark Kerr, *The Uses of the University* (New York, NY: Harper and Row, 1963); Carlos Kruytbosch and Sheldon Messinger, "Unequal Peers: The Situation of Researchers at Berkeley," *American Behavioral Scientist*, vol. 11, May-June 1968, pp. 33-44; and Albert H. Teich, "Research Centers and Non-Faculty Researchers: A New Academic Role," Phillips and Shen, op. cit., footnote 1, pp. 91-108.

[4] Kruytbosch and Messinger, op. cit., footnote 3; Teich, op. cit., footnote 3.

[5] National Research Council, op. cit., footnote 1, p. 69.

The growth of marginal positions (and the organized research units that often employ them) signals a change in university structure driven by environmental uncertainties, new obligations to industrial patrons, and tension between educational and research values. Just the sheer capital investment in research and development requires highly-skilled full-time staff to maintain operations. Universities' initial responses to reductions in research support have been to reduce costs, operate more efficiently, and secure as much flexibility as possible so that shrinkage, if necessary, will be both possible and less painful. Marginal positions and research units give universities flexibility in personnel and administration that traditional faculty positions and department structures do not permit. Simply put, marginal positions are more readily emptied and reallocated than are tenured and tenure-track faculty, and research units are easier to dissolve than departments. This buffer of temporary workers follows a trend in the private sector toward hiring more in-house contractors and short-term employees. Universities are also building bridges to alternate sources of funding, such as industry and State government, in particular by targeting research projects and centers to industry and State interests.

Despite the apparently sound reasons for increasing the ranks of marginal scientists, these positions affect the career prospects of incumbents, the scientific research that they do, and ultimately the academic work force. Marginal scientists are a significant scientific resource. The importance of their research can be documented from their publication and citation records. Moreover, the work done in these marginal positions also contributes to the productivity of other scientists and indirectly assists academic search committees by providing a longer "track record" with which to evaluate job candidates. But their time in these marginal positions also has costs.[7]

For example, there is no job security: employment usually ends when a project ends. Such positions have limited academic "rights," such as claims on laboratory and office space or access to seed money and equipment. Within the university, marginal scientists are dependent on others to provide part-time teaching or research employment to complete their salaries, to gain access to equipment, and thus are indebted to those who bestow such favors. In relations with the larger scientific community, occupants of marginal positions are at a competitive disadvantage because they do not have an established laboratory. Overall, such positions have relatively poor career prospects. Some who choose to remain are driven out as "too senior" to occupy such posts.

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[6] National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), p. 188.

[7] Edward J. Hackett, "Science in the Steady State: The Changing Research University and Federal Funding," OTA contractor report, 1987.

Marginal positions are an extension of the scientific apprenticeship system. But the appeal of flexible graduate education and postdoctoral training may lose its charm as a "permanent" marginal role. As a hybrid of the German *privatdocent* and the English fellowship, the marginal position encourages scientists to acquire new skills, prove themselves, and seek faculty openings. As a creature of Federal research support, marginal positions redirect scientists' careers in ways that diminish both professional autonomy and rewards. From both an institutional and Federal perspective, however, marginals represent a convenient hedge against both the squeeze of faculty tenure and retirements. Better understanding of this journeyman Ph.D. talent pool is needed.

Box 3-G. — Impact of a Federal Research Mission: The Apollo Program

The Apollo program is a widely acknowledged example of a Federal research mission that succeeded in quickly marshaling and developing the scientific and engineering resources needed to achieve a national goal. During the early-1960s National Aeronautics and Space Administration (NASA) recruited staff for the agency; pressured its contractors to recruit the technical people who would prove indispensable as systems engineers, project managers, and support personnel; and through a well-publicized grant program, supported university research in all 50 States.[1]

But NASA did not—and probably could not—have anticipated all the long-term consequences of its recruitment policies. NASA officials accepted the conclusion of the Gilliland Report (so named for its chairman) that the Nation faced a shortage of scientists and engineers by 1970, only to discover 4 years later that they were contributing to a surplus of technical people that the economy could no longer absorb. By then, NASA was faced with the need to start trimming its own work force. And here the agency failed to make the orderly transition to the post-Apollo period that Director Webb and his associates anticipated.[2]

The long-term effects of these separations affected NASA's ability to carry on much of its research, or to plan new flight projects. It was not that the proportion of NASA scientists and engineers to total agency employment declined. Quite the contrary. As a single category, they constituted just over one-half of NASA permanent employees. But there were fewer scientists and engineers engaged in hands-on research. There no longer were as many technicians available to support professional staff; the sharpest decrease in the number of bench-level scientists and engineers was in the age range from 30 to 39—precisely those whose research ideas were most likely to lead to flight projects a decade or more down the road.[3]

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[1] Arnold S. Levine, "The Apollo Program: Science and Engineering Personnel Demand Created by a Federal Research Mission," OTA contractor report, 1986; and W. Henry Lambright, *Launching NASA's Sustaining University Program*, Limited Advance Edition (Inter-University Case Program, Inc., 1969).

[2] Arnold S. Levine, *Managing NASA in the Apollo Era* (Washington, DC: National Aeronautics and Space Administration, Scientific & Technical Information Branch, 1982), p. 136.

[3] This discussion is based on Hans Mark and Arnold Levine, *The Management of Research Institutions — A Look at Government Laboratories* (Washington, DC: National Aeronautics and Space Administration, Scientific & Technical Information Branch, 1984),

Yet Apollo did create research capabilities that outlasted the program that created them. Because Apollo drew on all of NASA's resources, it compelled each center's managers to think of themselves as parts of a much larger organization. During the 1960s the "research" and the "development" centers tended to become more like each other; centers like the Ames and Langley Research Centers, with a mixture of smaller projects, weathered the budget cuts at the end of the decade better than those, like Marshall, with enormous development projects that were winding down. The older National Advisory Committee for Aeronautics centers found themselves with a broad range of skills in aeronautics, life sciences, and spacecraft design, many of them conferred by Apollo.

The impact of Apollo on scientists and engineers employed by NASA contractors was even more complex. Some remained in space-related programs; other moved on to comparable work in the aircraft industry; managers at higher levels moved back and forth between executive positions in industry, NASA, and the Defense Department. On balance, NASA played a stabilizing role in the aerospace industry; as employment on Apollo declined, professionals became available for commercial or defense-related work elsewhere. As for those who were laid off when NASA contracts were completed, the majority soon found comparable work, except among older engineers.[4] "In a fast-moving market, the needs of employers may change by the time entering students graduate."[5] This describes rather well what happened to many of the graduate students that NASA sponsored in the 1960s. Although the unemployment rates for scientists and engineers in the early-1970s was relatively low, they were much higher than they had been only 3 to 4 years earlier — four-and-one-half times as high for engineers.[6]

What are the longer-term implications of Apollo for the management of Federal research missions? Three observations can be made. First, Apollo embodied a certain approach to the management of large-scale endeavors that became very influential. As Webb put it, ". . . it is the new and different way of doing things — of organizing the use of knowledge and technology and human and material resources — rather than the new things themselves that is of most importance. . . ."[7] This implies that projects of such

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pp. 140, 142.

[4] Levine, op. cit., footnote 1, 1986.

[5] U.S. Congress, Office of Technology Assessment, *Demographic Trends and the Scientific and Engineering Work Force* (Washington, DC: U.S. Government Printing Office, December 1985), p. 25.

[6] National Science Foundation, *1972 Manpower Report of the President* (Washington, DC: U.S. Government Printing Office, March 1972), p. 121.

complexity require a new kind of manager: someone with a profound knowledge of the science and technology that the mission demands, with the ability to motivate the government and contractor workers involved. Of necessity, such people are rare.

Problems arise when a style or discipline appropriate to one kind of program is transferred to another. The same management approach — and even many of the same managers — that worked for Apollo was applied to the development of the Space Shuttle. It could certainly be argued that Apollo and the Shuttle were comparable as projects of inordinate complexity and technical difficulty. But for all its sophistication, Apollo was simple and its principles were well understood. No new technology was required in most instances. The Shuttle is far more complex and, until the Challenger tragedy, brought with it problems more like those of a commercial enterprise than of a government agency program. This suggests a second conclusion. Precisely because endeavors such as Apollo, the Space Shuttle, the War on Cancer, and the Strategic Defensive Initiative (SDI) are not routine, it is seldom possible to specify in advance the personnel needs of each one. Apollo was an exceptionally discrete, well-defined program with one main objective and many secondary ones. This is less true of the Space Shuttle or SDI and holds least of all for the War on Cancer.[8] NASA knew when it had achieved the goals of Apollo; comparable criteria of success are still lacking for these other programs.

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7. James E. Webb, *Space Age Management: The Large-Scale Approach* (New York, NY: McGraw-Hill, 1969), p. 61.

8. Kenneth E. Studer and Daryl E. Chubin, *The Cancer Mission: Social Contexts of Biomedical Research* (Beverly Hills, CA: Sage Publications, 1980), ch. 3.

Box 3-H. — Industrial Research on Campus: Effects on Biotechnology Students

One aspect of the "steady state" of academic science is the growing importance of industrial research support. With waning growth in Federal support, industrial values and practices associated with industry funding would seem to portend change in the academic milieu. While changes do occur, they are less dramatic than some have feared.[1]

Industry-sponsored research has grown more important on many American campuses in the past two decades, and particularly during the 1980s. However, industry funds are still a relatively small part of the university research budget. In real dollars, Federal research funding at universities rose 700 percent between 1953 and 1968, and by less than 20 percent in the subsequent 15 years. Meanwhile, beginning in the mid-1970s, American industry entered an expansive phase of research and development. In some cases — notably that of biotechnology — increased industry support included new institutional arrangements with universities, such as the establishment of entire industry-funded laboratories. Today, about 6 percent of university research is paid for by industry (and more in some fields), and this proportion is growing.

This reversal of the longstanding trend in increasing Federal support has disrupted scientists. Some laud the introduction of real-world priorities into academic research and the training of future researchers, particularly in engineering. They believe that subsidized academic scientists and students should tackle the current problems of society and industry.

Others see dangers in these new relationships. They cite risks of graduate students imbibing new, short-term, commercial values. The success of science, this line of argument maintains, involves the pursuit of research topics solely on their scientific merits; a student who is constrained by industrial support may not develop the judgment to identify truly important topics. In addition, some think, industry's emphasis on applied research may damage the traditional academic strength of basic research, and proprietary secrecy may inhibit the free exchange of information on which science is thought to thrive.

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[1] Michael E. Gluck, "Industrial Support of University Training and Research: Implications for Scientific Training in the 'Steady State'," OTA contractor report, 1987.

A survey of 693 life science graduate students and postdoctoral fellows at 6 research universities suggests that the influence of biotechnology firms on graduate students is substantial, but not much more constraining than any other funding influence.[2] The survey indicated that 19 percent of students and fellows surveyed received funds — research or training grants, salaries, or scholarships — directly from industry. Another 15 percent received no direct industry support, but worked under faculty advisors whose research was supported by industry. About 14 percent said their faculty advisors owned stock in biotechnology companies, but only a few of these students received funds from these companies. A separate survey indicated that only 5 percent of biotechnology faculty received more than 60 percent of their research support from industry (a somewhat smaller proportion of faculty than in chemistry or engineering).[3]

The conditions attached to such support are important in determining the influence of industry on the socialization of scientists. Just what is required in return for the funds? Industry funding may restrict research topics, or require students and fellows to work for the firm that supports them. In the extreme, such restrictions could result in a narrower education, with less room for initiative, than is typical in government-supported education.

In practice, some conditions are attached to most funding. There may be slightly stronger conditions on industry money than those attached to Federal grants, but there is no evidence that such conditions affect the ability of students to do independent research. Of 43 students and fellows with industry training grants or scholarships, 3 reported that they were expected to work on prescribed research problems, 3 must work for the supporting firms in the summer, and 9 must perform other activities for the firms' benefit. (It is not clear how much Federal support — particularly training grants — is given with similar strings attached, but Federal basic research funding generally does not restrict recipients' research topics.) Of the six universities involved in the student and faculty survey, two (Harvard and Massachusetts Institute of Technology) forbid firms from requiring trainees to perform such services.[4]

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[2] Michael Gluck et al., "University-Industry Relationships in the Life Sciences: Implications for Students and Post-Doctoral Fellows," *Research Policy*, vol. 16, 1987, pp. 327-336. The authors warn that the data in their study come from the largest research universities in the country, and that risks could well be greater at the smaller institutions. They caution also against generalizing the results of this study to chemistry, engineering, or other fields with large industrial involvements, since their resources and research opportunities may differ substantially.

[3] David Blumenthal et al., "Industry Support of University Research in Biotechnology: An Industry Perspective," *Science*, vol. 231, June 13, 1986, pp. 1361-1366.

Some have expressed the concern that faculty may be distracted by their industry work from normal academic activities, and that students' socialization could thereby suffer. The process of socialization is at the heart of graduate education. The traditions and values of science are transmitted — largely by the faculty advisor's example — along with its methods. However, surveyed professors receiving research support from industry report significantly more university and professional activities than their colleagues without such support. They also report spending more time with students. Even faculty members holding equity in biotechnology companies show no neglect of their academic duties. (These results probably reflect the fact that companies form relationships with the more productive faculty members.)

Another aspect of socialization is the kind of career expectations transmitted. Here the survey finds no correlation with industry support; students and fellows with such support are no more or less likely than others to desire academic careers, for example.

Finally, for a very small percentage of students, who are supported by companies in which their faculty advisors own stock, there is the risk of conflict of interest; the advisor might direct students' research for the benefit of the company rather than that of the students.

The data suggest some changes associated with industry support. In a few cases industrial training grants and scholarships may be associated with increased trade secrecy, delayed publication, and inhibited scholarly discussion; data, however are only suggestive, not conclusive, on this point. The survey also indicates that trainees with industrial support publish significantly less than others; the evidence shows, however, that this pattern reflects individual predilections rather than effects of industry funding. (Faculty with industry research support, for example, publish more than their peers without such support.)

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[4] Gluck, op. cit., footnote 1.

These risks of industry funding are tempered by several conditions: 1) they are infrequent, 2) industry funds are outweighed overwhelmingly in university training efforts by Federal funds, and 3) they are subject to safeguards by university policies, which may provide guidelines for the industry involvement with students and fellows. Many institutions have already adopted guidelines promoting open communication of research, for example, and some have limited the conditions that may be attached to industry support.

It is important to recognize that academic research agendas and students' research and career interests are steered by many external factors, as well as their own predilections. The interests of faculty advisers, Federal funding availability, and the opportunities and limitations offered by available equipment and facilities all guide students. The as-yet unresolved fear is that industry may guide academic research in the United States more strongly and disruptively than other influences.

Box 3-1. — Preserving Young Science and Engineering Talent in Universities: Two European Programs

In western Europe, as in the United States, the problem of recruiting and retaining new research talent in universities has become a matter of concern. Stagnant demand for university faculty and high industrial salaries have drawn many bright young researchers away from universities. Several countries established programs to counter this trend.[1] The following examples are cited as innovations that could be adapted to the U.S. system of higher education and employment of scientists and engineers.

Federal Republic of Germany: Heisenberg Fellowships and the Fiebinger Plan

In West Germany, heavy faculty recruitments in the 1970s, in response to that decade's rising enrollments, left universities with little demand for additional faculty; budget cuts in the early-1980s further depressed demand. At the same time, growing enrollments produced many talented young researchers, some of whom have pursued the *Habilitation*, a postdoctoral degree considered a necessary qualification for appointment to a full chairholder post in a German university. To retain this pool of specialized talent in universities, where they may be ready to assume professorial positions when the 1990s bring retirements of many current faculty members, the government in 1978 established the Heisenberg Fellowships.

The holder of the *Habilitation* is considered to be prepared solely for the academic labor market, with a research training too inflexible for industrial research positions. In addition, the average recipient of this degree is over 38 years old, too old for entry into industry. Surveys show that only about 20 percent of the recently qualified *Habilitierten* have otained the tenured professorships traditionally associated with the degree.

The Heisenberg program, run jointly by federal and provincial authorities, provides *Habilitierten* and others holding specialized academic degrees with university research positions for up to 6 years. The program thus retains these highly-trained and talented people within the orbit of the university, holding them in reserve.

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[1] Based on a review of European programs by Guy Neave, "Science and Engineering Work Force Policies: Western Europe," OTA contractor report, 1987.

The Heisenberg Fellowships were considered a temporary measure, to bridge a short-term slump in academic demand. By 1983, however, it had become obvious that most of the first group of recipients would not find academic positions before their fellowships expired and that the faculty job market was unlikely to improve substantially before the 1990s.

The Federal Government responded by mandating artificial improvements in the job market. Under the Fiebinger Plan (named after the university president who proposed it), all 11 provincial governments are called on to increase the number of academic posts by 1 percent each year from 1985 to 1990. This measure will provide 200 additional jobs annually (at a cost of DM200,000 per job). The jobs in each province will be distributed by field according to assessments of needs for scientific and engineering research.

The Fiebinger Plan is large enough to maintain only one-fifth of new *Habilitierten* in universities. With faculty retirements not expected to turn upward until the 1990s, young researchers may still feel insecure about their futures. Some provinces, with this fact in mind, have encouraged early retirement of full professors, so that they may be replaced by younger staff (who, besides being young and creative, are at the bottom of the salary scale).

The United Kingdom: "New Blood"

Like the Federal Republic of Germany, the United Kingdom cut university budgets in the early-1980s. As in Germany, this step reduced opportunities to hire younger faculty; about 3,500 posts were abolished. Without new faculty, it was feared, British universities would fail to establish research programs in emerging fields — especially those considered important to the nation's high-technology future.

In response, the University Grants Committee in 1982 established a "New Blood" program to bring bright young researchers onto university staffs. A secondary aim was to shift the distribution of academic posts away from the humanities and toward the natural and applied sciences considered critical to the nation's scientific and economic future.

The program bears certain similarities to the German Fiebinger Plan. It funded academic research posts at universities, emphasizing new research lines of high promise, such as engineering, physics, the biological sciences, and information technology. University proposals for particular appointments were evaluated according to their potential impacts on the universities' research programs, and on the age distribution of academic staffs. The program was limited to researchers under the age of 35.

In the 3 academic years beginning with 1983-84, the program approved 792 posts at a total cost of about 22 million pounds. The average grant was £22,000 in the natural sciences, medicine, and technology, and £16,000 in the humanities. Physics accounted for 25 percent of the posts established, engineering 18 percent, medicine 16 percent, the biological sciences 11 percent, the social sciences 9 percent, the humanities 8 percent, mathematics 8 percent, agriculture and veterinary studies 3 percent, and education 1 percent. Funding covers not only salaries, but also research expenses. Universities assume responsibility for financing after the initial grants are made.

Chapter 4

Engineering Education

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Chapter 4

Engineering Education

Engineering education reflects a labor market oriented to production and design, and is sensitive to technological change. About 80 percent of all engineers and most engineering Ph.D.s are employed by industry (see figure 4-1). Engineering enrollments strongly reflect the health and research and development (R&D) activity of relevant industries (often linked to Federal R&D priorities). Engineers can enter the professional R&D work force with baccalaureate or master's degrees, earning more than other new college graduates, and almost as much as Ph.D. engineers. Three of every four new engineering baccalaureate recipients go immediately to industry jobs (see figure 4-2).

STUDENTS AND INSTITUTIONS: AGENTS OF SUPPLY AND DEMAND

The demand for engineers is variable and, in the long term, unpredictable. Most adjustment occurs within the existing work force. Rapidly growing industries sometimes boost demand temporarily beyond the ability of work force reserves and academic institutions to produce engineers. However, employers, the work force, and students adapt well to changing markets. The supply of engineers is augmented and buffered by auxiliary supplies that can be drawn on in times of shortages and transition: engineers and scientists in related fields, technicians and technologists, recent retirees, and engineering managers.

Despite this elasticity in supply, spot shortages and surpluses always occur, and shortages may continue over the longer term. Rapid demand growth usually creates transitory shortages, as seen recently in electronics and computer engineering. Likewise, rapid cutbacks create surpluses, as happened in the early-1980s in petroleum and chemical engineering. Continuing shortages in some areas, such as manufacturing and nuclear engineering, may reflect not only strong demand but also continuing lack of student interest and university ability or commitment to training students in those areas. While the shortages of the early-1980s have eased, employers report shortages in computer and aerospace engineering.[1]

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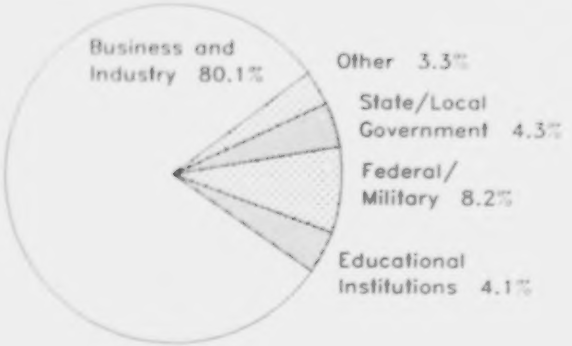
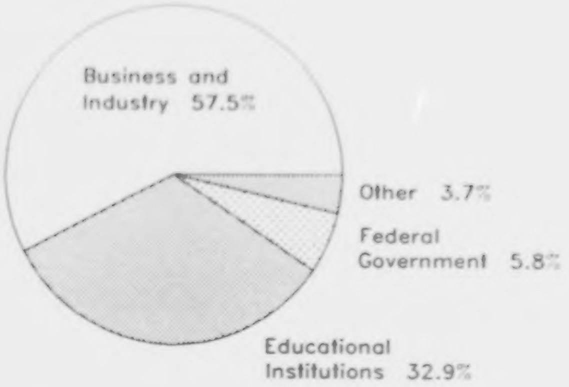
[1] According to National Science Foundation surveys of employers and other indicators (the Deutsch, Shea & Evans High Technology Recruitment Index; the Job Offers Index of the College Placement Council; and starting salaries as reported by the College Placement Council, the Recent College Graduate Survey, and the Engineering Manpower Commission). National Science Board, *Science and Engineering Indicators* —

Figure 4-1.—Where Engineers Work, 1985 and 1988


All engineers, 1988

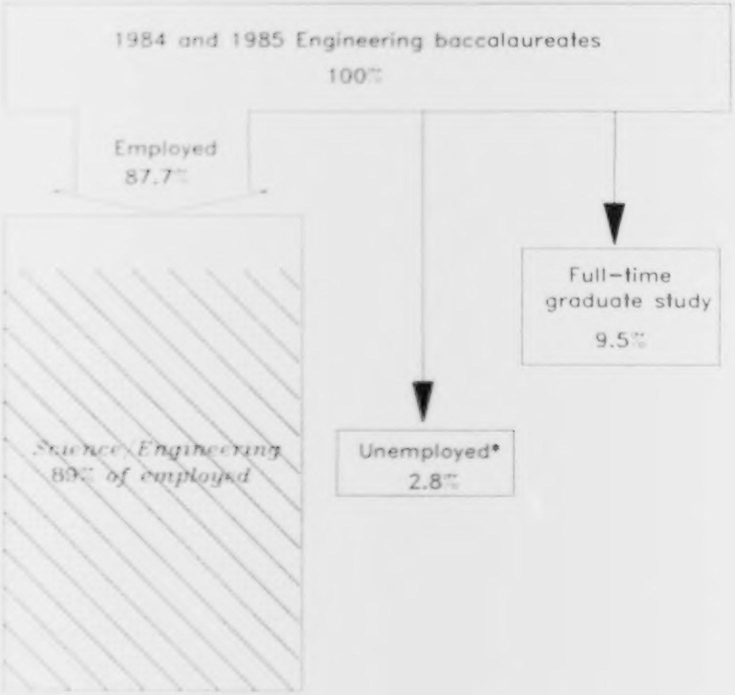
NOTE: n(all engineers) = 2,849,800


Ph. D. engineers, 1985

NOTE: n(Ph.D. engineers) = 65,900
Reflects latest available data.

SOURCE: National Science Foundation, U.S. Scientists and Engineers: 1988, Estimates, NSF 88-322 (Washington, DC: 1988), pp. 8-9; and National Science Foundation, Doctoral Scientists and Engineers: A Decade of Change, NSF 88-302 (Washington, DC: 1988), pp. 50-51.

Figure 4-2.—Career Paths of 1984 and 1985 Engineering Baccalaureates in 1986


1984 and 1985 Engineering baccalaureates
100%
Employed
87.7%
Full-time graduate study
9.5%
Unemployed*
2.8%
Science/Engineering
89% of employed

*Includes those not in labor force.

NOTE: Total graduates = 164,500
Part-time graduate study = 23,000 (14%)
Employed in industry = 110,900 (67%)

SOURCE: National Science Foundation, Characteristics of Recent Science and Engineering Graduates: 1986, NSF 87-321 (Washington, DC: 1987), pp. 13-15, 43-44, 47.

The supply of baccalaureate-level engineers does not distribute evenly, in numbers of students or talent, among engineering fields and specialties (see figure 4-3 and table 4-1). Students oversubscribe highly-visible, highly-paid fields such as electrical engineering and shun important but lower profile areas such as chemical and mining engineering. Electrical engineering has grown 250 percent and has been responsible for nearly one-half of the growth in engineering between 1977 and 1987, while civil and nuclear engineering have stagnated.

Many argue that the United States could better utilize and support its engineers, particularly with well-trained technicians and improved engineering management. Because engineering knowledge becomes outmoded, it is important to have a steady influx of newly-trained engineers and to refresh the knowledge of mid-career engineers through continuing education. Industry and the engineering community have a strong interest in lifelong education and retraining, as well as in undergraduate engineering education.

Perennial Themes: Quantity and Quality

The strength of the next generation of engineers depends on two things:

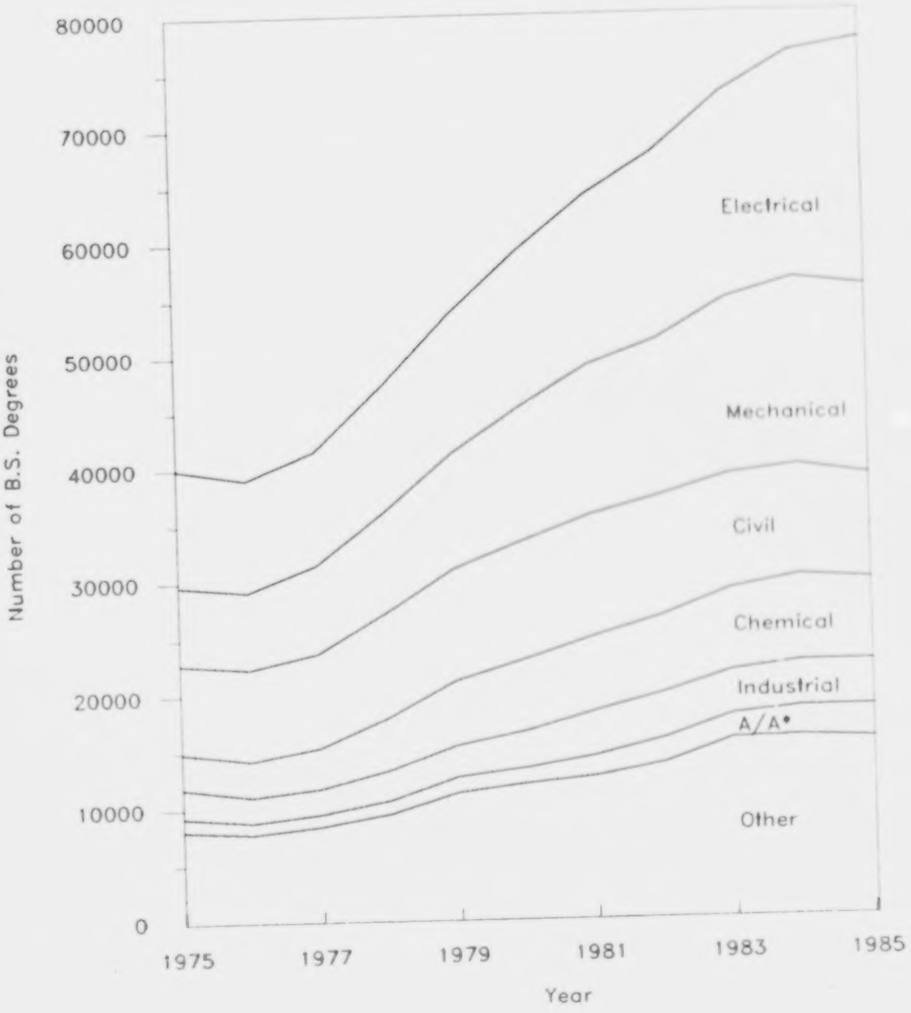
- students in the engineering pipeline, who shape the size and diversity of the supply of new engineers; and
- engineering institutions, whose capacity, facilities, faculty, and attitude determine the quality of engineering education.

The quality of engineering education deserves at least as much attention as the number of students. Quality depends on the structure of the curriculum, the academic preparation of students, and the capability of engineering institutions to provide effective faculty, facilities, equipment, and ties with industry.[2] Continuing concerns over the quality of engineering education, and its appropriateness for employers, students, and society as a whole have fueled longstanding issues over the structure and content of engineering education (see box 4-A and appendix D).

1987, NSB 87-1 (Washington, DC: National Science Foundation, 1987), pp. 64-65.

[2] National Research Council, *The Effects on Quality of Adjustments in Engineering Labor Markets* (Washington, DC: National Academy Press, 1988). J.F. Coates, Inc., *Forces Shaping the Future of Engineering Education* (Washington, DC: American Society of Mechanical Engineers, June 1987); Charles E. Hutchinson and Carol B. Muller, "Educating Engineers: In Praise of Diversity," *Issues in Science and Technology*, vol. 4, summer 1988, pp. 71-74.

Figure 4-3.–B.S. Degrees in Engineering, by Subfield, 1975–85



*A/A = Aeronautical/astronautical

SOURCE: National Science Foundation, Women and Minorities in Science and Engineering, NSF 88-301 (Washington, DC: 1988), p. 197.

Table 4-1. — Growth Rate of Engineering B.S. Awards, by Specialty, 1977-87

	Growth rate 1977-87 (in percent)	Number of BS degrees awarded, 1987	Growth rate 1985-87 (in percent)
Computer	292	5,012	18
Aerospace	217	2,845	7
Electrical	156	25,198	14
Industrial	153	4,572	6
Mechanical	113	16,056	-6
ALL ENGINEERING	89	75,735	-3
Chemical	43	5,129	-29
Mining	15	628	-32
Civil	2	8,388	-11
Nuclear	-34	324	-24

SOURCE: Engineering Manpower Commission.

Universities report continuing, significant shortages of Ph.D. engineers for academic posts, due primarily to the strong industry demand (and accompanying high salaries) for engineers at all levels. Compared to the sciences, engineering has relatively few Ph.D.s; doctorate engineers make up only 3 percent of working engineers. Unlike Ph.D. scientists, they work mainly in industry. Ensuring an adequate, qualified supply of Ph.D. engineers is more problematic than sustaining undergraduates. Academia must compete with the high salaries, state-of-the-art equipment, and good working conditions of industry.[3] Substantial financial sacrifices usually must be made to undertake a Ph.D., in return for very modest financial gains in increased lifetime salary. The prestige of a Ph.D. in engineering is less than in the sciences. Overall, the rewards of obtaining an engineering Ph.D. are seen as small by many young U.S. citizens, so that foreign citizens have come to dominate U.S. graduate engineering programs and junior faculties.

Computer science, a hybrid of mathematics and engineering, is an applied science that in many aspects is closely allied with engineering. Much of the industry demand for computer scientists has been interchangeable with demand for electrical engineers. Other computer scientists do theoretical research. The newly-formed field of computer engineering is the fastest growing of all engineering specialties. As in engineering generally, over three-quarters of baccalaureate computer scientists go directly into industry, where salary offers are almost as high as those in engineering.

The Federal Government influences the demand for engineers through R&D initiatives, general R&D spending, and economic and fiscal policies which affect industry R&D spending and manufacturing. Policies in technology transfer, innovation, and university-industry relations affect engineers because of their crosscutting role in industrial R&D and developing new technologies into products and services.

As in science, the Federal Government has much greater influence on graduate education than on undergraduate education. Many engineering students, like students in all areas, depend on the Federal Government for financial support. Likewise, there is demand on the Federal Government to help bolster the capacity of colleges and universities to prepare engineers, particularly in terms of maintaining quality equipment, facilities, and faculty. The skewed demography of engineering — few women and minorities, but growing numbers of foreign students — has spurred calls for Federal action.

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[3] The National Science Foundation reports that in 1986 the median annual salaries of recent engineering baccalaureates (1984 and 1985 graduates) are $30,000 in industry and $19,600 in educational institutions — not including full-time graduate students. National Science Foundation, *Characteristics of Recent Science/Engineering Graduates: 1986*, NSF 87-321 (Washington, DC: U.S. Government Printing Office, 1987), p. 83.

This chapter focuses on the many components of undergraduate engineering education. In addition to trends in enrollments and degrees, it is important to look at how the pool is formed and constrained by the curriculum, employer needs, and changes both in the engineering community and the wider culture.

Trends in Enrollments and Degrees

Engineering and computer science were the fastest growing areas of study in universities from the early-1970s to the mid-1980s. The largest increase has been in bachelor's engineering awards, which rose from 38,000 to over 77,000 between 1975 and 1985,[4] while baccalaureates in all fields grew less than 20 percent (see figure 4-4). During this boom, engineering bachelor's degrees went from 4.5 percent to 8 percent of all bachelor's degrees (see figure 4-5).

The surge in engineering baccalaureates ended in 1985, reflecting the downturn in the job market, particularly in the electronics and computer industries. Current undergraduate enrollments, coupled with the declining college-age population, indicate a substantial decline in conferred engineering baccalaureates through the 1990s.[5] Master's degrees continue their steady climb.

Engineering Ph.D.s, like those in the sciences, peaked in 1970-72 and then declined rapidly. The continuing decline in engineering Ph.D. awards relative to bachelor's awards in the 1970s testifies to the attractive job market for bachelor's- and master's-level engineers. Over the past 3 years, engineering doctorate awards have increased and regained their 1975 level. About 4,000 engineering Ph.D.s were awarded in 1987.[6]

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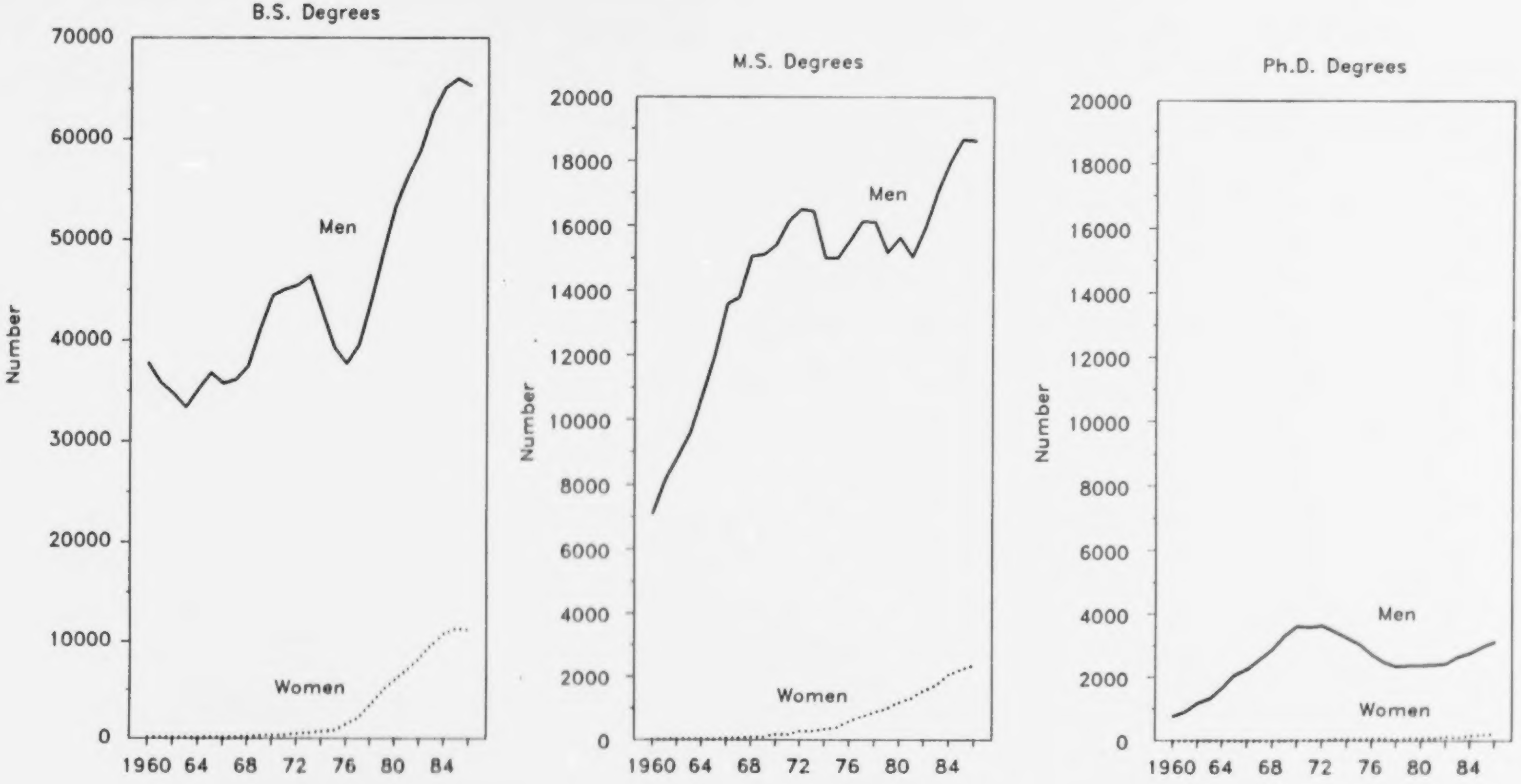
[4] Engineering Manpower Commission, *Engineering and Technology Degrees* (Washington, DC: American Association of Engineering Societies, published annually). Unless otherwise noted, engineering degree data are from the Engineering Manpower Commission. The commission estimates at all degree levels tend to be slightly higher than numbers reported by the National Research Council and the U.S. Department of Education's National Center for Statistics, but follow a similar pattern.

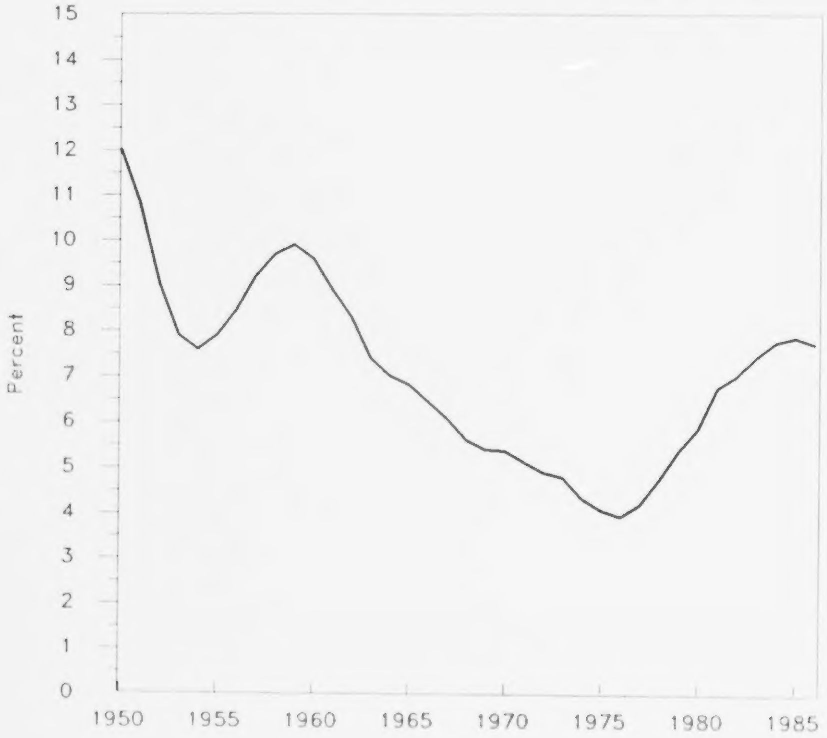
[5] Commission on Professionals in Science and Technology, Washington, DC, unpublished data. Enrollment and degree data are from the U.S. Department of Education, National Center for Statistics; freshmen intentions from Cooperative Institutional Research Program, University of California, Los Angeles, *The American Freshman: National Norms for Fall, 1985* (Los Angeles, CA: Higher Education Research Institute, December 1985).

Figure 4-4.–Engineering Degrees by Sex and Level, 1960-86



SOURCE: Betty M. Vetter and Henry Hertzfeld, "Federal Funding of Science and Engineering Education: Effect on Output of Scientists and Engineers, 1945–1985," OTA contractor report, 1987, based on U.S. Department of Education data.

Figure 4–5.–Engineering Baccalaureates as a Percentage of All B.A./B.S. Degrees



SOURCE: Betty M. Vetter and Henry Hertzfeld, "Federal Funding of Science and Engineering Education: Effect on Output of Scientists and Engineers, 1945–1985," OTA contractor report, 1987, based on U.S. Department of Education data.

Graduate enrollments have been rising since 1978, signaling slight increases in engineering Ph.D. awards at least into the early-1990s. Although much of the recent increase has been due to foreign students on temporary visas, who now receive over 40 percent of engineering Ph.D.s, graduate enrollments of U.S. students have been rising as well, albeit very slowly.[7]

In 1986, over 41,000 B.S. degrees were awarded in computer science.[8] The field has boomed since the late 1970s. Similarly, between 1977 and 1985, the number of computer science graduate students rose more than 15 percent per year, from 9,000 to nearly 30,000.[9] In 1986, about 400 computer science Ph.D.s were awarded, compared to a few dozen 10 years before.[10] With a declining supply of mathematics Ph.D.s and a growing pool of computer science and computer engineering Ph.D.s, this growth may dwindle as the field matures.[11] Just under one-half of recent computer science Ph.D.s work in universities and colleges, with equal numbers in industry. Academic demand is still high and should continue to increase, though it has eased significantly from the near-crisis of the 1970s, when existing and potential faculty and graduate students flocked to lucrative jobs in industry.

Recruitment to the Undergraduate Pool

The size of the engineering pool is set early in the educational pipeline, more so than in other majors. A hierarchical and sequential curriculum, designed around the early-committed student, makes it difficult to enter from other majors. The gatekeeping function of high school mathematics preparation and college mathematics performance excludes most students. This intensive approach means that high school science and

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6. Engineering Manpower Commission data. However, about 40 percent of these are foreign students on temporary visas; this proportion has been increasing steadily.

[7] National Science Foundation, *Academic Science/Engineering: Graduate Enrollments and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), p. 81.

[8] U.S. Department of Education, Center for Education Statistics data.

[9] All graduate students in all institutions. National Science Foundation, op. cit., footnote 7, p. 74. In the past few years, full-time enrollments have been rising faster than part-time enrollments. Among full-time students, foreign enrollments are continuing to rise faster than U.S. enrollments. Foreign students, including those on permanent visas, are now about 40 percent of full-time computer science enrollments.

[10] National Research Council, *Doctorate Recipients From U.S. Universities* (Washington, DC: 1986). Twenty percent were awarded to foreign citizens, but most of those were on permanent visas.

[11] The Computer Science Board, Committee on Research Funding in Computer Science, *Imbalance Between Growth and Funding in Academic Computer Science: Two Trends Colliding* (Washington, DC: April 1986), pp. 8-9.

mathematics preparation strongly governs first the choice of engineering and then the persistence of those students who choose engineering majors.

Most freshman engineers choose engineering during the junior and senior years in high school.[12] While mathematics and science are taught in high school as "foundation" courses for technical careers, there are very few "pre-engineering" programs — and they are often vocationally-oriented. Most are targeted to minorities or the gifted.[13] Students plan engineering majors on the basis of other influences, such as relatives, parents of friends, movies, television programs, books, imagination, and perceptions (accurate or not) of a job market that offers attractive starting salaries. These influences are poorly understood.[14]

Freshman interest in engineering reflects trends in the job market, and anticipates the supply of baccalaureates a few years down the road. Interest in engineering peaked in 1982, when over 12 percent of all college freshman planned to major in engineering (B.S. degrees peaked in 1985-86). Among 1987 freshman, fewer than 10 percent were interested in engineering majors.[15] Freshman interest in computer sciences followed a similar, but more exaggerated, rise and fall. Both trends show pronounced differences when students are disaggregated by sex (see figure 4-6).

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[12] Report of the Task Force on the Engineering Student Pipeline, "Findings and Recommendations," *Engineering Education*, vol. 78, May 1988, pp. 778-780.

[13] See Gillian F. Clark, "Pre-College Programs Key to Minority Engineering Efforts," *Black Issues in Higher Education*, Oct. 15, 1987, pp. 9-10; and National Action Council on Minorities in Engineering, *Pre-College Program Directory* (New York, NY: 1985). Two examples: Philadelphia Regional Introduction for Minorities to Engineering (PRIME) offers enrichment, student internships, counseling, field trips, industry programs, and publicizes educational success stories for junior high and high school minority students in southeastern Pennsylvania. Alexander Tobin and Richard Woodring, "PRIME: A Model Precollege Minority Program," *Engineering Education*, May 1988, pp. 747-749. The Department of Energy's Prefreshman Engineering Program (PREP) awards money to colleges and universities for summer research and instruction in mathematics, science, and engineering for junior high school girls and minorities. There is extensive cost-sharing with local industry; the 1985 budget was $280,000. In 1985 this program reached over 2,700 students. Students are selected by school teachers and counselors, primarily on the basis of interest and ability. About two-thirds of students who participate in PREP go on to pursue science or engineering in college. U.S. Department of Energy, *University Research & Scientific Education Programs of the U.S. Department of Energy*, DOE/ER-0296 (Washington, DC: September 1986), p. 9.

[14] See U.S. Congress, Office of Technology Assessment, *Elementary and Secondary Education for Science and Engineering*, OTA-SET-TM-41 (Washington, DC: U.S. Government Printing Office, December 1988), chs. 1, 5. Engineering-related programs in and outside of school might augment the pool of students interested in and prepared for engineering majors in college.

[15] Cooperative Institutional Research Program, University of California-Los Angeles, *The American Freshman* (Los Angeles, CA: Higher Education Research Programs, published annually).

The Relation Between Salaries and Supply

As with other fields, engineering attracts students for a combination of reasons, ranging from innate interest and family pressures to a desire for a stable job and good pay. Many cite the high salaries for engineers as a leading reason for many students' interest. Engineers receive higher starting salaries than any other baccalureate-level specialist, about $29,000 (compared to $21,000 for the average college graduate).[16] The substantial salary advantage for engineers has been longstanding and has been unchanged in real terms. For a decade beginning in 1973, real salaries rose faster than average, but have since declined. The stability of starting salaries over the long term suggests that, despite temporary variations, supply and demand are relatively well matched within the 4 to 5 years it takes to produce a B.S. "generation."

Generally the financial profile of undergraduate engineers resembles that of other students. Engineering students are slightly more likely than science students to have loans, and less likely to use grants only. Engineering students who borrow tend to acquire slightly higher than average debt, possibly in part because they anticipate higher than average salaries. The difference in loan burdens is not great, however (especially taking into account the higher salaries of engineers), and debt does not affect the choice of undergraduate major. There is no good evidence that higher loan burdens are driving students to choose higher-salaried fields such as engineering.[17]

To the extent that money figures into students' goals, higher and more stable pay for engineers, whether in academia, government, or industry, influences their career choice.[18] Freshmen planning to major in electrical engineering, chemical engineering, or

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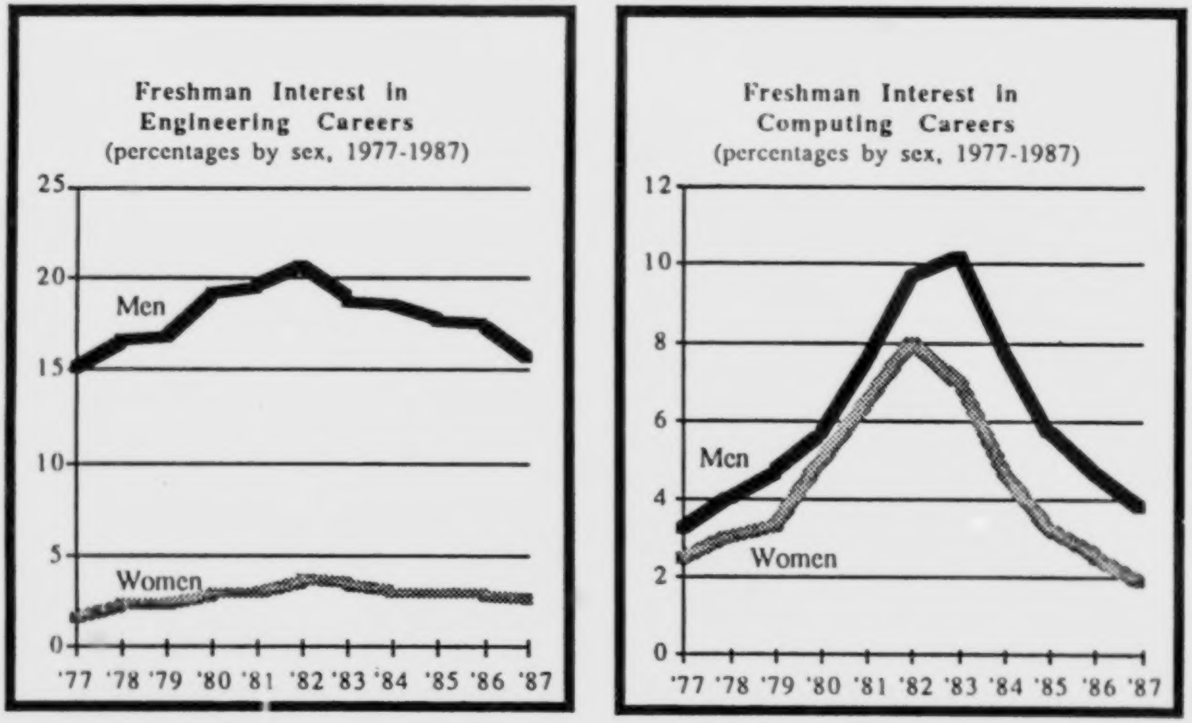
16. *Manpower Comments*, January/February 1988, p. 25.

17. Edward P. St. John and Jay Noell, "Student Loans and Higher Education Opportunities: Evidence on Access, Persistence, and Choice of Major," prepared for the Fourth Annual NASSGAP/NCHELP Research Network Conference, June 3, 1987; and Applied Systems Institute, Inc., "Financial Assistance, Education Debt and Starting Salaries of Science and Engineering Graduates: Evidence From the 1985 Survey of Recent College Graduates," OTA contractor report, 1987, based on Recent College Graduate Survey data. As long as B.S. engineering salaries remain strong, students respond well without additional financial incentives. While engineering students are more likely than others to do cooperative work-study during college, such programs are not a significant source of funds for most students.

18. Kenneth C. Green, personal communication, 1987. Data are from the Cooperative Institutional Research Program.

Figure 4-6.-Freshman Interest in Engineering and Computing Careers, by Sex, 1977-87



SOURCE: Cooperative Institutional Research Program, The American Freshman: National Norms for Fall 1987 (Los Angeles, CA: University of California, Los Angeles, December 1987), p.6.

computer science are more job- and money-oriented in their college plans than other freshmen, including other science/engineering majors, and are more likely to cite job opportunities and high salaries as very important reasons for attending college.

Attrition

Attrition of undergraduate engineering majors, like science majors, is significant (around 20 to 30 percent), but varies greatly by campus, and with trends in the job market.[19] During the engineering boom of the late-1970s, transfers into engineering compensated for attrition. Attrition is substantially lower for Asians, higher for women and Hispanics, and even higher for Blacks (see figure 4-7). Attrition is compounded when students need 4.5 or 5 years, a not uncommon period, to complete the baccalaureate in engineering.

Attrition, however, can be reduced. Effective preparation and retention programs have been demonstrated with women and minorities, and it is likely that such programs can be applied to the majority of the population. Few universities and colleges have recruitment and retention programs for students wishing to choose engineering majors after the freshman year. Transfers into engineering from 2-year institutions seem to provide a quick response to ups and downs in the job market, but national data on this phenomenon are lacking.[20]

Expanding and Diversifying the Pool of Engineers

Engineering is a large and diverse profession. Educators concerned about bolstering the supply of young engineers look to both talented white male students entering other fields, and to women and minorities, groups that have so far been poorly represented in engineering. Recruitment strategies can generally be applied to all students; minorities and women must, however, be reached early and given stronger academic preparation, particularly in mathematics. Recommendations to expand and diversify the pool of engineering students are listed in box 4-B.

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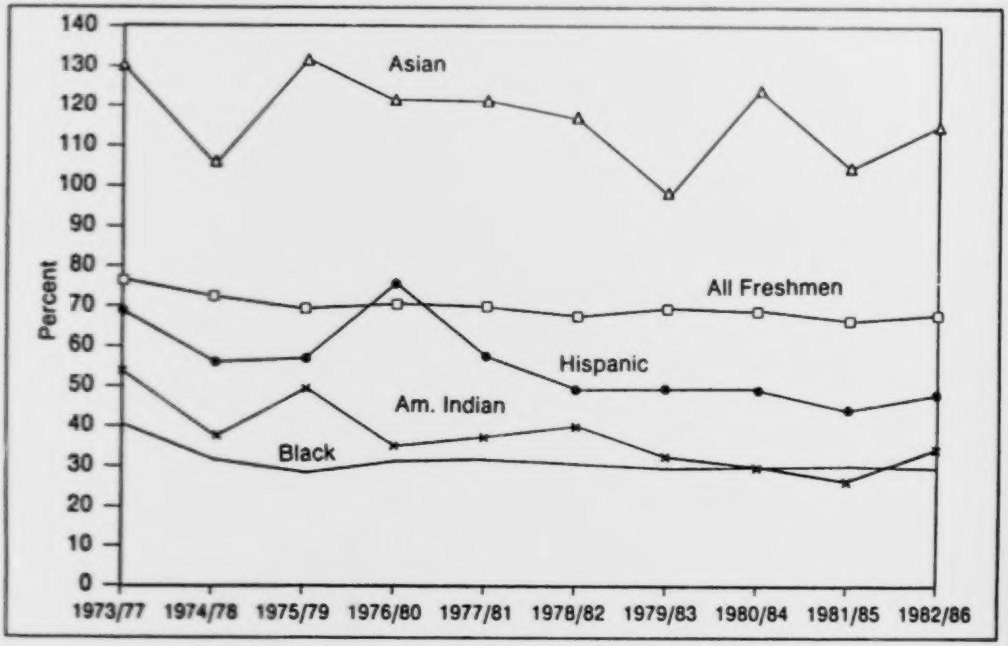
[19] Betty M. Vetter, "Demographics of the Engineering Student Pipeline," *Engineering Education*, vol. 78, No. 8, May 1988, pp. 737-739, based on Engineering Manpower Commission data.

[20] The growth of "3+2" programs, which funnel students from liberal arts colleges into engineering programs, also highlights the transfer function. Again, however, national data are elusive.

Figure 4-7.–Retention Rates of Engineering Freshmen, 1973/77–1982/86



NOTE: Asian student retention rates greater than 100% reflect the fact that the drop-out rate among freshmen and sophmores is less than the input at the junior year from two-year institutions.

SOURCE: Betty M. Vetter, "Demographics of the Engineering Student Pipeline," Engineering Education, vol. 78, No. 8, May 1988, p. 739.

Women

Women have made much faster gains in engineering than in any other field, largely because their historic participation rate was miniscule (see figure 4-8). Women earn about 15 percent of engineering baccalaureates, up from less than 1 percent in 1970. Engineering and computer science have gained popularity at the expense of the life and social sciences. Gains have also been significant at the master's level and, to a lesser extent, at the Ph.D. level, where women earn about 7 percent of science and engineering Ph.D.s. Gains vary by field; female engineers tend to concentrate in chemical, petroleum, and industrial engineering, and are less likely to choose, for example, electrical engineering.

Current trends suggest a slowing of these gains. Freshman engineering enrollments of women have leveled off at about 16 percent. Despite the plateau, the rapid gains were unprecedented. Understanding this change could well illuminate the mechanisms of career selection at work in the vast population of college students who ignore or are not welcomed by certain fields.[21] This was the case for women in engineering before the 1970s.

Gains for women have been slow in engineering employment, especially in faculty jobs. The small number of women in tenure-track engineering faculty positions, between 100 and 200 nationwide, indicates the persistence of barriers.[22] At nearly all levels of education and experience, there is a salary bias against women. For the most recent graduates, however, women and men receive equivalent starting salaries, in part probably due to sustained years of strong demand for engineers.[23]

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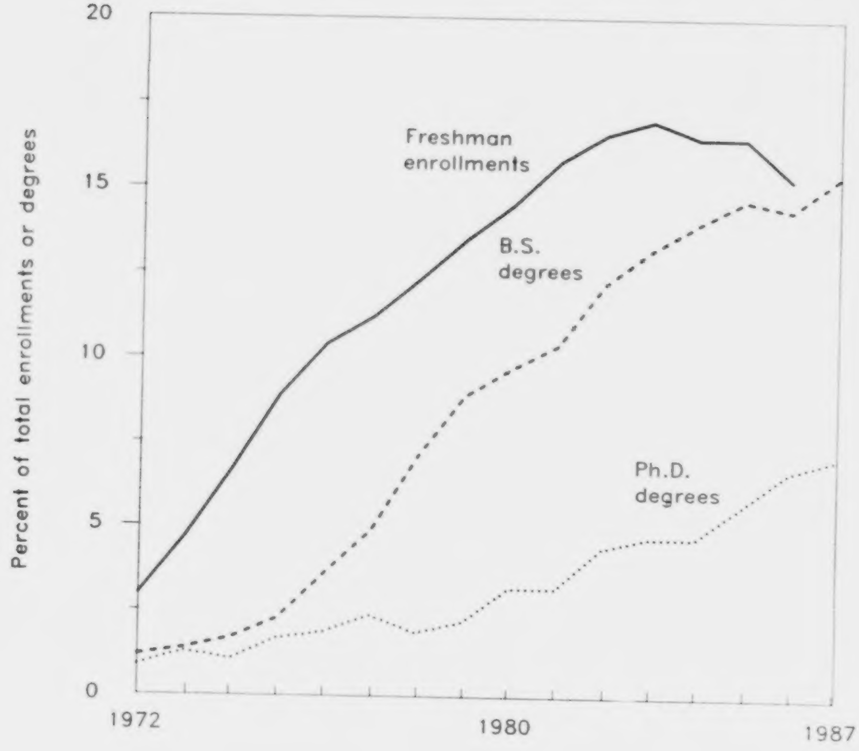
[21] Carolyn M. Jagacinski et al., "Factors Influencing the Choice of an Engineering Career," *IEEE Transactions on Education*, vol. E-28, No. 1, February 1985, pp. 36-42.

[22] Attitudes of male engineers — especially those with 5 or more years of work experience, no Ph.D., and little daily contact with female engineers — toward female engineers in the nonacademic workplace tend to be negative. Anil Saigal, "Women Engineers: An Insight Into Their Problems," *Engineering Education*, December 1987, pp. 194-195; William K. LeBold, "Women in Engineering and Science: An Undergraduate Research Perspective," *Women: Their Underrepresentation and Career Differentials in Science and Engineering*, Proceedings of a Workshop, Office of Scientific and Engineering Personnel, National Research Council (Washington, DC: National Academy Press, 1987), pp. 49-98.

[23] The National Science Foundation reports that among recent engineering baccalaureates (1984 and 1985 graduates who were employed full time, not including full-time graduate students) men and women had identical annual salaries. By comparison, in all scientific fields, men receive salaries several thousand dollars greater than those women receive. National Science Foundation, op. cit., footnote, 3 p. 82. An industry

Figure 4-8.-Women in Engineering, 1972-87



SOURCE: Engineering Manpower Commission data.

22.

Computer science has become an increasingly common field of graduate study and employment for women. Nine percent of employed computer science Ph.D.s are women, the highest proportion outside the social and biological sciences. In science and engineering, women earned 16 percent of U.S.-earned Ph.D.s and one-third of the bachelor's degrees in 1986.[24] One in five full-time graduate students in the United States is a woman (the percentage is higher, perhaps one-third, for U.S. students, since most foreign students are male).[25]

Minorities

Blacks and Hispanics have made slow inroads into engineering. Although minorities are interested in engineering majors, they are generally poorly prepared academically and often lack the study habits needed to succeed in the unfamiliar environment of college. Their attrition is much higher than that of whites or Asians; about one-half of Hispanic, and one-third of Black engineering freshmen complete undergraduate engineering programs, compared with an average for all freshmen of 70 percent. Together, Blacks, Hispanics, and Native Americans are about 5 percent of engineers. Asian-Americans are an additional 7 percent. The small increase in the Blacks' and Hispanics' share of engineering degrees dwindles when compared to the concurrent rise in the proportion of Blacks and Hispanics among the college-age population (see table 4-2). Blacks and Hispanics are scarcer at the Ph.D. level in engineering than in the sciences; perhaps a dozen Blacks and two dozen Hispanics receive engineering Ph.D.s each year. The story is similar in computer sciences.

Asian-Americans have become a much larger proportion of undergraduate engineering majors than their representation in the general population (about 1 percent) would lead one to expect. Most of these degree recipients are foreign-born Asian immigrants. Asian-Americans (including foreign-born Asians on permanent visas) receive over 13 percent of engineering Ph.D.s granted to U.S. citizens.

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perspective on salary differentials is also instructive. As part of an annual profile, Robert R. Jones ("R&D Industry Developing An Entirely New Look," *Research & Development*, vol. 30, May 1988, pp. 78-80) reports that ". . . the highest median salary for women (women in industry) remains below the lowest for men (men in universities) by 17.1%." In some areas, the "entirely new look" remains all too familiar.

[24] National Research Council, op. cit., footnote 10. Women earned only 12 percent of all Ph.D.s, since almost all foreign students are male. Bachelor's data are from the U.S. Department of Education, National Center for Statistics.

[25] National Science Foundation, op. cit., footnote 9, p. 41.

Table 4-2. — Engineering Degrees, by Level and Race/Ethnicity, 1987
(in percent)

	B.S.	M.S.	All Ph.D.s	U.S. Ph.D.s 1986
Blacks	2.9	1.5	0.4	1.4
Hispanics[a]	3.1	1.6	0.6	2.0
American Indians	0.2	0.1	0.1	0.3
Asian-Americans	6.7	7.3	5.6	15.2
ALL MINORITIES	12.9	10.5	6.7	19.0[b]

[a] Includes degrees awarded by the University of Puerto Rico (UPR). If these data are not included, Hispanics are 2.4% of B.S. degrees. UPR data would not change M.S. or Ph.D. results.

[b] U.S. minorities as a percent of engineering Ph.D.s awarded to U.S. citizens. "U.S." includes foreign citizens on permanent visas.

SOURCE: Richard A. Ellis, "Engineering and Engineering Technology Degrees, 1987," *Engineering Education*, vol. 78, No. 8, May 1988, p. 785.

A supportive campus environment and institutional commitment to minorities are particularly important for helping minorities graduate.[26] Special support programs can substantially reduce attrition for Blacks and Hispanics in engineering.[27] Most programs have a strong campus base, but depend on government and private funds as well as university support. Successful programs provide peer support, tutoring, and community-building among minority students. All emphasize the importance of precollege preparation, call for consistent retention efforts from middle school through college, and high school career guidance by engineering professional societies.[28] Today, there are indeed success stories (see box 4-C).

Ten institutions produce one-third of Black B.S. engineers; three of these are historically Black colleges or universities. The University of Puerto Rico produces over 20 percent of Hispanic engineers; 20 institutions produce half of the rest.[29] At least in the near term, the concentration of minority engineering students in a small number of institutions argues that a few specially targeted and well-supported intervention programs could reach a large proportion of minority students.

Latecomers to engineering are another potential source of engineers. Significant numbers of engineers decide to enter engineering during college; in periods of high demand, as many as one-quarter of B.S. graduates.[30] Most of these enter from other scientific or technical majors. Despite evidence of this potential for recruitment during college, engineering curricula are aimed at students who come to college having chosen the engineering major. Little effort is made at the college level to attract nonengineering majors, though engineering educators recognize this as a key issue and are now mobilizing to address it.[31]

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[26] Richard C. Richardson, Jr. et al., "Graduating Minority Students," *Change*, May/June 1987, pp. 20-27; and Edmund W. Gordon, "Educating More Minority Engineers," *Technology Review*, July 1988, pp. 69-73.

[27] Ray Landis, "The Case for Minority Engineering Programs," *Engineering Education*, May 1988, pp. 756-761. For Black freshmen engineers at the University of California, attrition (out of engineering or school altogether) after 3 years was 87 percent; for Blacks in the Minority Engineering Program, attrition was 36 percent. The Minority Engineering Program has had similar success with Hispanic students.

The private National Action Council for Minorities in Engineering (NACME) is the leader in coordinating and disseminating information on minorities in engineering and intervention programs. NACME's $1.1 million funding for the first 4 years came from the Sloan Foundation. The next 4 years gathered corporate support and eventually some National Science Foundation funding. NACME and most intervention programs also receive substantial in-kind support from corporations (e.g., faculty loans) and colleges and universities.

[28] National Academy of Engineering, *Engineering Education and Practice in the United States: Engineering Infrastructure Diagramming and Modeling* (Washington, DC: National Academy Press, 1986); and National Academy of Engineering, *Engineering Undergraduate Education* (Washington, DC: National Academy Press, 1986).

[29] For a review of national minority engineering programs, and data on top-producing institutions of minority engineers, see "Special Report: Engineering Education," *Black Issues in Higher Education*, vol. 4, No. 15, Oct. 15, 1987, pp. 9, 12-15; and *Engineering Education*, vol. 78, May 1988.

Foreign Engineering Students

The influx of foreign students to American universities is particularly apparent in engineering. Foreign students have received a steady 7 to 9 percent of bachelor's engineering degrees since the mid-1970s. Their share of master's degrees increased slightly during the 1970s to around 25 percent, which has held steady since 1980. Foreign students are much more likely than U.S. students to continue for Ph.D.s. Over 40 percent of recent engineering Ph.D.s have been awarded to foreign students on temporary visas, up from 30 percent in 1975 (see figure 4-9).[32] About 70 percent of the foreign students who receive engineering Ph.D.s are Asian.[33]

The high demand for engineers has made it more attractive and easier for foreign students to study and work in the United States. About one-half of foreign engineers (at all degree levels) stay on to work in the United States after graduation.[34] The shortage of engineering faculty has made university and college departments particularly dependent on foreign Ph.D.s. The proportion of foreign engineers among young faculty (age 35 or younger) has risen from 10 percent to nearly 50 percent since 1975.[35]

Foreign students have also joined the rush to computer science. Foreign students on temporary visas received nearly one-third of the computer science Ph.D.s awarded in

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[30] Anne Scanley and Engin Holstrom, Government-University-Industry Roundtable, National Academy of Sciences, personal communication, September 1987. Analysis of the 1984 followup on the 1980 Cooperative Institutional Research Program, University of California, Los Angeles, data on freshmen show that 20 to 25 percent of engineering majors in colleges and universities were recruited to that major during college.

[31] J. Ray Bowen, "The Engineering Student Pipeline," *Engineering Education*, vol. 78, May 1988, pp. 733-734.

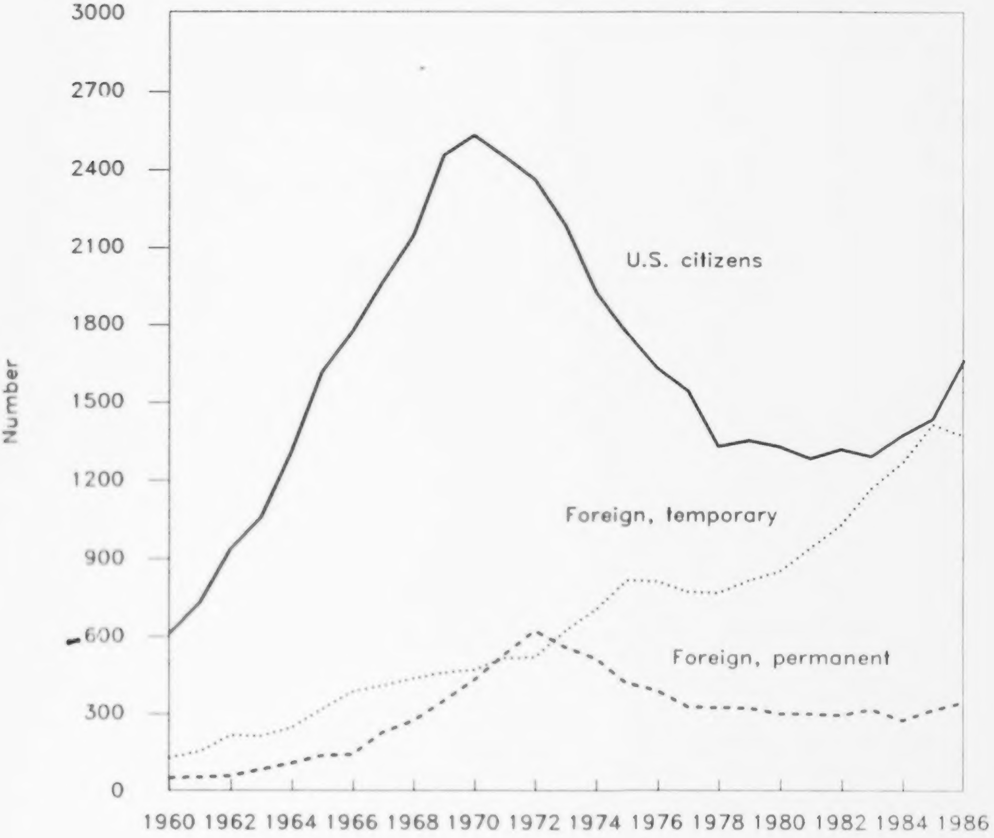
[32] National Research Council, op. cit., footnote 10.

[33] National Science Foundation, *Foreign Citizens in U.S. Science and Engineering: History, Status, and Outlook* (Washington, DC: December 1986), p. xiii. The share of U.S. citizens receiving Ph.D.s increased in 1986.

[34] Michael G. Finn, Oak Ridge Associated Universities, "Foreign National Scientists and Engineers in the Labor Force, 1972-1982," June 1985, p. 5.

[35] Engineering Manpower Commission survey, in Vetter, op. cit., footnote 19, p. 739.

Figure 4-9.-Engineering Ph.D. Awards by Visa Status, 1960-86



SOURCE: National Science Foundation, Foreign Citizens in U.S. Science and Engineering: History, Status, and Outlook, NSF 86-305 revised (Washington, DC: 1986), p. 96.

1986, up from 11 percent in 1977.[36] Most foreign computer scientists — at both the bachelor's and Ph.D. levels — remain to work in the United States, more than in any other field.[37] Foreign computer scientists are important as new hires in the electronics and computer industries as well as academia. In Silicon Valley companies, they may constitute as much as one-third of the work force.[38] Foreign nationals comprise over one-third of all university computer science faculty, the highest ratio among all fields of science or engineering.

Employers and universities testify to the high quality of foreign students and engineers.[39] However, the large numbers of foreign students and faculty have raised concerns in the engineering education community. Some foreign faculty, for example, have been said to discriminate against women, reflecting their cultural backgrounds. (Of course, native engineering faculty are not always free of such prejudice either.) The Department of Defense (DoD) has also expressed concern about adequate supplies of American citizens to work as engineers on defense projects. For this, DoD has taken initiatives to bring more women and minorities into the talent pool.[40]

THE QUALITY ISSUE IN ENGINEERING EDUCATION

The quality of engineering education rests mainly in the hands of the institution. Each engineering college oversees its own admissions, curriculum, student programs, faculty, facilities, and laboratories. In other words, institutions delegate (or concede) responsibility for executing quality standards to disciplines, departments, and individual faculty.[41]

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36. National Research Council, *Doctorate Recipients From U.S. Universities, Summary Report 1986* (Washington, DC: National Academy Press, 1987).

37. U.S. Congress, General Accounting Office, *Plans of Foreign Ph.D. Candidates: Postgraduate Plans of U.S. Trained Foreign Students in Science/Engineering*, GAO/RCED-86-102FS (Washington, DC: February 1986), p. 3.

38. National Science Foundation, op. cit., footnote 33, p. 75, charts 5.1 and 5.2.

39. For example, Stanford S. Penner, "Tapping the Wave of Talented Immigrants," *Issues in Science and Technology*, vol. 4, spring 1988, pp. 76-80; and National Research Council, *Foreign and Foreign-Born Engineers: Infusing Talent, Raising Issues* (Washington, DC: National Academy Press, 1988).

40. Two major initiatives include the Center for the Advancement of Science, Engineering and Technology, a Department of Defense-sponsored project which is compiling information on successful intervention programs; and the National Consortium for the Physical Sciences, a consortium of Federal agencies, major corporations, and universities that is working to increase support and research opportunities for women and minority graduate students.

41. Guidance from engineering societies, especially the American Society for

Except for national missions such as the Apollo program, the Federal Governnment has had little direct role in engineering education.[42] While the project-based programs of the mission agencies have had massive effects on the production of engineers, little money has been directed toward science and engineering education per se. The concern with engineering problems, especially at DoD, the National Aeronautics and Space Administration, the Department of Transportation, and to a lesser extent the Department of Energy and the Environmental Protection Agency, has underwritten the support for human resources. In contrast with the founding of the National Science Foundation's (NSF) Engineering Directorate (and the addition of engineering to its charter), engineering research centers and education have been formally recognized.

Faculty

Attracting and keeping good faculty is critical for engineering schools. Because of strong industrial demand for engineers in the past 10 years, universities and colleges seeking faculty to serve high undergraduate enrollments face a continuing shortage of Ph.D. engineers interested in academic positions, particularly in fast-growing fields such as electrical and computer engineering. The American Society for Engineering Education (ASEE) reports that about 9 percent of the 20,000 faculty posts are unfilled. And anticipated high retirements (in most academic fields) in the 1990s should again increase demand. Universities would like to be able to hire more U.S. faculty than are available.[43]

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42. As recently as 1982, no Federal agency targeted funds specifically for undergraduate engineering education. According to a General Accounting Office analysis, a total of 38 programs in 11 agencies spent $240 million on engineering education in fiscal year 1981, but more than 80 percent of this was in the form of student loan guarantees and a little over 10 percent went to the Merchant Marine and Coast Guard Academies. U.S. Congress, General Accounting Office, *No Federal Programs are Designed Primarily to Support Engineering Education, But Many Do*, GAO/PAD-82-20 (Washington, DC: May 14, 1982).

43. A.S. Wilke and W.A. Shaw, "The Faculty Shortage: Comparing National and Local Data," *Engineering Education*, January 1988, pp. 233-235. The interplay of supply and demand, and inferences about quality that arise at times of imbalance, is discussed in National Research Council, *The Effects on Quality of Adjustments in Engineering Labor Markets* (Washington, DC: National Academy Press, 1988). The new Federal law prohibiting retirement due to age is raising anxieties in universities about differential impacts on faculty hiring by field.

Faculty and graduate student increases have not kept pace with increasing enrollments, and the faculty-to-student ratio has declined. In the engineering boom between 1973 and 1983, undergraduate enrollments grew 80 percent while faculty numbers grew 10 percent. ASEE recommends ratios of 12 or 14 to 1 for undergraduate engineering education, which would require a 20 to 25 percent increase in current faculty numbers.[44] Shortages are worst at predominantly undergraduate institutions.[45] In response to the demand for faculty, engineering schools are using more adjunct, industrial, part-time, and other nontraditional faculty.[46]

Methods of attracting engineers into academia now include, for example, NSF's Presidential Young Investigator awards, which encourage industry matching funds. Some States and universities created special salary schedules or add-ons for engineering faculty; these helped recruit and retain faculty. Faculty development — career long learning — is often cited as a priority for engineering professors.[47]

Access to Equipment and Facilities

State-of-the-art equipment is particularly important in engineering education, and contributes significantly to its high cost.[48] Since 1985 engineering faculty cite laboratory equipment and building facilities as two of their most pressing problems.[49] This is both a catch-up problem, to make up for past underinvestment, and a continuing problem because of the rising costs of equipment and maintenance.

Equipment problems vary by field. They are chronic in manufacturing engineering, where equipment comes in large and expensive pieces. Universities may tailor their course offerings according to availability of certain kinds of low-cost or donated equipment; the result may be significant gaps in course offering where equipment is not available.

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[44] W. Edward Lear, *The Quality of Engineering Education Programs* (Washington, DC: American Society for Engineering Education, 1986), p. 139.

[45] Paul Doigan and Mack Gilkeson, "Engineering Faculty Demographics: ASEE Faculty & Graduate Student Survey, Part II, *Engineering Education*, January 1987, p. 208.

[46] Ibid., p. 212.

[47] American Society for Engineering Education, *A National Action Agenda for Engineering Education* (Washington, DC: 1987), pp. 18-22.

[48] The American Society for Engineering Education in 1986 estimated $8,400 for laboratory costs for educating a B.S. engineer, including for personnel, operating costs, and amortized capital cost. Lear, op. cit., footnote 44, p. 141.

[49] According to a 1985 American Society for Engineering Education survey, reported in Doigan and Gilkeson, op. cit., footnote 45, p. 212. For 1987 survey results, see Paul Doigan and Mack Gilkeson, "Who Are We? Engineering and Engineering Technology Faculty Survey, fall 1987, Part II," *Engineering Education*, vol. 78, November 1988, pp. 109-113.

In engineering as in the sciences, most laboratory equipment is obsolete and in extremely short supply, classroom and laboratory space is inadequate, and buildings often need renovation or replacement. The problems are particularly acute at teaching-oriented institutions that do not receive extensive corporate or Federal research support; these institutions produce one-half of all B.S. engineers. Even where up-to-date equipment is available as a result of corporate gifts, funds to maintain, insure, or repair it are often lacking. The easing of enrollment pressure in the last 3 years does not resolve the problem. A very large number of engineering institutions are still training students with little hands-on experimental experience, in overcrowded laboratories, using equipment so obsolete it bears no resemblance to what the students will encounter when they graduate.

Increased spending on engineering equipment in the past few years has mitigated but not eliminated the immediate problem.[50] Maintenance and new needs will continue to press for permanent changes in funding of university equipment. These needs impinge on all areas of science; engineering is especially affected because it is so equipment-intensive.

The unanimous recommendations of recent studies are for major Federal funding and incentives that would sharply increase State and corporate contributions to institutions whose primary mission is undergraduate engineering education. One engineering community study estimated a need to double laboratory space and spend nearly $3 billion for instructional laboratory equipment to match to the peak quality levels of 1972, and defray a current annual maintenance cost of about $30 million.[51]

Computers and Communications Technologies

Computers and computer-based equipment have become integrated into day-to-day engineering teaching and laboratories, and have created an entirely new education industry of televised, videotaped, and telecommunicated instruction.[52]

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[50] National Science Board, op. cit., footnote 1, pp. 80-84 and 256-263.

[51] Lear, op. cit., footnote 44, p. 140.

[52] Ibid., pp. 73-122.

Computers and Undergraduate Engineering Education

Computer and communications applications in engineering are diverse. They include decision and design aids, desktop computers, teaching aids, flexible manufacturing systems, computer-aided design and engineering workstations (CAD/CAM/CAE), graphics, computerized sensors and nondestructive testing, simulation, computerized machine tools and robotics, supercomputers, sophisticated portable calculators, instructional video, and communication networks.

Intelligent engineering tools demand human partners with new skills and roles, emphasizing problem recognition, unusual problem solving, visualization, flexibility, information evaluation and synthesis, and decisionmaking. Networking may extend the engineer's role in communicating with management, the public, regulators, foreign customers and sources, and sales personnel. These new needs demand changes in the education of engineers, technologists, and technical managers. Students must understand and practice with the tools they will be using in the future.

The current pressing concern is adequate student access to modern workstations and computer-based equipment. Universities have difficulty equipping and maintaining their classrooms, offices, and laboratories and rewiring buildings, despite special Federal equipment funding and industry donations. Arranging access to industry equipment through special programs or cooperative education has not proved easy or sufficient. Federal tax incentives have helped but not inspired industry donations; student fees are insufficient to cover costs; States have had limited effect.[53] In the longer term, new issues may arise as changes in engineering jobs and computer-based training restructure the engineering curriculum.

Distance Learning

Long-distance delivery of education through video recordings and telecommunications networks opens new arenas for engineering education. Distance learning is particularly important for part-time, advanced students at the master's level, and for continuing engineering education. Electronic instruction takes several forms. On campus, televised courses can reach more students at a variety of times, easing overcrowding in engineering classrooms. It provides employees at job sites with remote access to instruction emanating from universities, companies, and third parties. Instruction can be real time and interactive, or recorded for later use. Video and electronic technologies make access to education convenient, flexible, broader, and less expensive. They make possible more diverse, up-to-date, tailored courses and permit certain economies of distribution.

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[53] U.S. Congress, Office of Technology Assessment, *Technology, Innovation, and Regional Economic Development*, OTA-STI-238 (Washington, DC: U.S. Government Printing Office, July 1984).

The Association for Media-Based Continuing Education for Engineers (AMCEE) was founded as a consortium in 1976, with funds from NSF and the Sloan Foundation, to increase the national effectiveness of continuing education for engineers. Membership has grown from 12 to 33 universities, serving thousands of engineering students; the current catalog lists more than 550 video courses. Building on this success, in 1982 the National Technological University (NTU) was created (see box 4-D). In addition to courses by satellite, NTU offers special symposia, teleconferences, and other services.

Electronic instruction is spreading. In 1986 nine major programs using instructional television to provide M.S. programs in engineering disciplines were in operation or under development. Operated by public and private universities, the programs used various delivery methods to reach part-time students, usually at their job sites. More than 40 regional systems are in operation today. About two dozen major universities, in the past 20 years, have awarded more than 3,500 M.S. degrees to engineers who complete degree requirements in this way.[54]

Cooperative Education

Cooperative education or "co-op" — student work for academic credit and (usually) pay in industrial or corporate settings — is particularly important for engineers. It provides unique career enhancement integrated with academic training, with irreplaceable hands-on experience, improved access to modern equipment, role models, education, training, career guidance, testing, and screening. Earnings help pay college expenses, but financial aid is not the primary goal, and co-op is a less effective means of financial aid than work-study and other aid programs.[55] Engineering co-op graduates, like other co-op students, tend to receive higher salaries and better jobs. Yet engineering co-op graduates are no less likely than other engineers to go on to graduate school.[56]

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[54] Lionel V. Baldwin, "Tune In for Professional Development," *Engineering Education*, April/May 1987, p. 679.

[55] James W. Wilson, Northeastern University, "Summary Report: Cooperative Education — A National Assessment," 1978, p. 22.

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Engineering and technology have dominated cooperative education since the concept was implemented in 1906 by a civil engineer at the University of Cincinnati.[57] Much of the 1970s' growth in co-op programs, however, was in trade, business, and liberal arts.[58] Slightly over 36,000 engineering and engineering technology undergraduates (less than 10 percent of undergraduate enrollments) are in co-op programs.[59]

Engineering students have various sorts of work experiences. In one survey of young engineers, 16 percent had co-op experience, 44 percent had other engineering-related employment, 31 percent had nonengineering employment, and 8 percent had no undergraduate work experience at all.[60] However, co-op engineering students are much more likely than working nonco-op students to have work related to their majors.[61]

Federal support for co-op programs was first specifically authorized in 1968 amendments to the Vocational Education Act of 1963 and Title IV-D of the Higher Education Act of 1965 (HEA). The first significant appropriations under this legislation were not made until 1973, when $10 million was awarded by the Department of Education as seed grants for universities to start co-op programs. The number of co-op programs increased rapidly, and took another leap following further amendments in 1976, which placed co-op education in Title VIII of the HEA (see figure 4-10).[62] Impact was limited, as funds tended to seed many small programs. Regulation changes in 1979, designed to encourage expansion of programs, successfully increased enrollments.

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[56] Sylvia J. Brown, *Cooperative Education and Career Development: A Comparative Study of Alumni* (Boston, MA: Northeastern University, Cooperative Education Research Center, 1976), pp. 36-38.

[57] Richard P. Nielsen et al., *An Employer's Guide to Cooperative Education* (Boston, MA: National Commission on Cooperative Education, 1987), p. 1.

[58] Wilson, op. cit., footnote 55, p. 46.

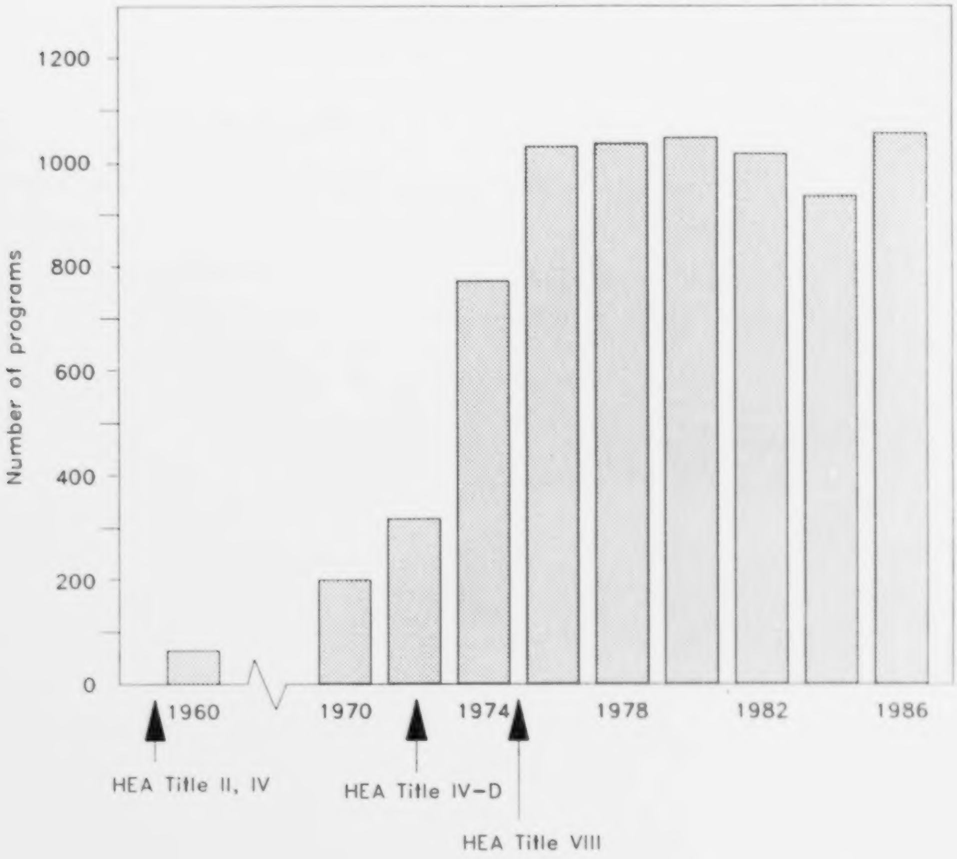
[59] James W. Wilson, Cooperative Education Research Center, Northeastern University, "Cooperative Education in the United States and Canada," 1986, survey data.

[60] Carolyn M. Jagacinski et al., "The Relationship Between Undergraduate Work Experience and Job Placement of Engineers," *Engineering Education*, January 1986, p. 233. The survey was limited to engineers who had graduated between 1961 and 1980 and who were working full time. They averaged 6 years since receipt of the baccalaureate.

[61] Brown, op. cit., footnote 56, p. 36.

[62] John Dromgoole et al., National Commission for Cooperative Education, "Change Management in Cooperative Education: The Expansion and Development of Title VIII Comprehensive Large Scale Co-op Programs," unpublished manuscript, n.d.

Figure 4-10.—Cooperative Education Programs, 1960–86



NOTES: Includes Canada (less than 5% of total programs).
In 1986, 1,016 U.S. programs enrolled 198,000 students.
Includes junior college programs, which account for about 40% of the total of both programs and students.
About 30% of cooperative education students are in engineering.

SOURCE: Cooperative Education Research Center, "Cooperative Education in the United States and Canada" (Boston, MA: Northeastern University, January 1987); and James W. Wilson, "Cooperative Education—A National Assessment" (Boston, MA: Cooperative Education Research Center, Northeastern University, April 1988).

State involvement in co-op programs has been small and sporadic. Foundations have also supported co-op education. The most important actors, the employers themselves, have generally not assumed a leadership role in coordinating the on- and off-campus experiences.[63] The Federal Government also has a lead role as an employer of co-op students, employing about 8,000.

UTILIZING AND UPGRADING THE ENGINEERING WORK FORCE

Continuing Education

Continuing engineering education is extensive and expanding.[64] Most engineers undertake continuing education during their careers; more that one-half of all engineers participate in some kind of training each year.[65] Concern about the supply of new engineers, rising costs, and improving corporate flexibility, industrial productivity, and efficiency has prompted investment and innovation in continuing education.

Continuing education is used to update specific technical skills. Companies invest more in formal continuing education and training for technicians than they do for Ph.D. engineers.[66] Young engineers are more likely than old ones to undertake such training. Although not strictly considered continuing education, extensive on-the-job training is usually required during the first year of engineering employment. It is not clear how much of this burden could be shifted to the universities or to joint university-industry programs. Much in-house training presumably is necessary to introduce new engineers to company equipment, procedures, and techniques.

Corporate needs have fostered many ad hoc arrangements with traditional educational institutions. In 1984, for example, General Motors (GM) contracted with 45

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63. National Research Council, "Engineering Education and Practice in the United States," *Engineering Undergraduate Education* (Washington, DC: National Academy Press, 1986), pp. 27-32.
64. Bruno O. Weinschel and Russel C. Jones, American Association of Engineering Societies, *Toward the More Effective Utilization of American Engineers*, (Washington, DC: American Association of Engineering Societies, 1986); Russel C. Jones and William K. LeBold, "Continuing Development to Enhance the Utilization of Engineers," *Engineering Education*, April/May 1986, pp. 669-673; and "Continuing Education," *Engineering Education*, April/May 1987, pp. 656-685.
65. National Research Council, *Engineering Education and Practice in the United States: Continuing Education of Engineers* (Washington, DC: National Academy Press, 1985), pp. 21-22.
66. Ibid., p. 22.

community colleges around the country for automotive technician training courses, with the college faculty receiving specialized training at GM.[67] Universities are offering more evening and short courses, televised and videotaped courses, and certificate programs. Industry contracts for technician training or continuing engineering education have become a significant revenue source for some engineering colleges and universities. The time and trouble of getting access to a desired course at a convenient time and place have prompted expansion of telecommunications-based distance continuing education, which allows employers to bring a specific course right into their offices or plant.[68]

Estimates of private investment in continuing education vary, but all indicate something on the order of tens of billions of dollars. Most is informal, on-the-job training — observing an experienced worker — but increasingly includes formal courses. Companies also pay about $10 billion annually in tuition for employees enrolled in conventional courses and degree programs.[69] The Federal Government also sponsors extensive retraining for both military and civilian technical employees.

These sums dwarf Federal education outlays. However, only large companies can afford extensive training. Corporate education expenditures correlate very strongly with R&D investment and ranking in the Fortune 500. Although society benefits, it is difficult for a company to recoup its investment when workers leave. Also, companies often reduce retraining support during business downturns, when retraining is most needed. Although many educational institutions are offering more continuing education, they often do not have the appropriate resources or faculty to do specialized mid-career engineering retraining in addition to their primary general teaching mission. Public investment in retraining could be justified on the value of a well-trained work force to the economy, and helping individuals who may be dislocated or made obsolete by technological advance. Overcoming disincentives for retraining may require public policies to encourage company and industry-wide retraining, support retraining of government employees, increase individual investment in retraining (e.g., through tuition credits), and assist colleges, universities, and third party education providers in developing programs.[70]

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[67] Steven L. Goldman, "The History of Engineering Education: Perennial Issues in the Supply and Training of Talent," OTA contractor report, 1987. Also see David F. Noble, *America by Design: Science, Technology and the Rise of Corporate Capitalism* (New York, NY: Knopf, 1977).

[68] Academic engineers can also benefit from continuing education; some argue that industry should play a larger role to keep engineering faculty abreast of industry advances and interests.

[69] A number of reports, especially in the *Wall Street Journal*, and in conversations with executives at IBM, Hewlett-Packard, Motorola, Hughes, DuPont, and other medium to large companies, refer to the practice by more and more companies of reducing their engineering work force to a core group and hiring more contract engineers on a project-by-project basis (Pamela Atkinson, University of California, Berkeley, personal communication, November 1988). This will remind engineers of the virtues of entrepreneurship in marketing their talents. See National Academy of Engineering, *Focus on the Future: A National Action Plan for Career-Long Education for Engineers* (Washington, DC: 1988).

Engineering Technicians and Technologists

Engineering technicians and technologists are vital support personnel in engineering practice and production. The vast majority of engineering technicians are employed in industry. There are over 1 million engineering technicians,[71] but their training and jobs are diverse and there is no well-accepted definition of technician or technologist. Electronics and electrical technicians are by far the largest category, accounting for over 40 percent of engineering technicians and technician-level degrees.[72] Major concerns are the supply of well-trained technicians, qualified at least at the 2-year associate level, and the capacity of institutions to train quality technicians.[73]

About 12,000 4-year bachelor's degrees and 14,000 2-year associate degrees were awarded in engineering technology in 1987 at programs surveyed by the Engineering

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[70] U.S. Congress, Office of Technology Assessment, *Technology and the Economic Transition*, TET-283 (Washington, DC: U.S. Government Printing Office, 1988), pp. 240-251, 385; and Richard M. Cyert and David C. Mowery (eds.), *Technology and Employment: Innovation and Growth in the U.S. Economy* (Washington, DC: National Academy Press, 1987).

[71] Betty M. Vetter and Eleanor L. Babco, *Professional Women and Minorities: A Manpower Data Resource Service*, 5th ed. (Washington, DC: Scientific Manpower Commission, August 1984), p. 198, table 7-31; and National Science Board, op. cit., footnote 1, pp. 56-57, 221.

[72] Estimates of the engineering technician population provided by Betty Vetter, Commission on Professionals in Science and Technology, based on Bureau of Labor Statistics data and the Engineering Manpower Commission's *Engineering and Technology Degrees* series. Vetter estimates 384,000 electrical/electronic technicians out of 984,000 total in 1985. The U.S. Department of Education's National Center for Statistics unpublished data on engineering technology/technician degrees are significantly higher than Engineering Manpower Commission data.

[73] National Science Foundation, *Emerging Issues in Science and Technology, 1982*, NSF 83-61 (Washington, DC: 1983), pp. 49-58; "Engineering Technology," *Engineering Education*, April/May 1987, pp. 724-755.

Manpower Commission.[74] Estimates of total associate level engineering degrees are on the order of 90,000 to 100,000.[75] Engineering technology programs have been growing rapidly; although there is some evidence of downturns in enrollments in the past few years.[76]

Technician and technology degrees are conferred by community colleges, 2- and 4-year city colleges, proprietary vocational-technical institutions, and to a lesser extent at State colleges and universities. Faculty tend to come from industry. In addition to formal degree programs, significant technician training and certification is done privately, through associations and companies. Most institutions are supported by tuition paid by students or employers.

Engineering technology and technician students and institutions have historically been outside the mainstream of U.S. science and engineering education, and beyond the reach of Federal engineering education programs. Though a source of engineering talent through mobility and training, they are often ignored in R&D policy. NSF, with its focus on universities, research, and Ph.D.s, has not been involved in technician training. Universities employ technicians, in science and engineering, but many of these are their own alumni. That situation is changing. The National Technicians Training Act, introduced (though not passed) in 1987, directed NSF to designate ten centers of excellence among community colleges to serve as clearinghouses and model training programs.[77]

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74. Richard A. Ellis, "Engineering and Engineering Technology Degrees, 1987," *Engineering Education*, May 1988, p. 792. The Engineering Manpower Commission collects partial data on 2- and 4-year accredited programs. These programs cover a majority, but by no means all, of formal 2- and 4-year programs. They do not cover certificate, pre-engineering, or less formal degree programs. Difficulties of definition of programs make data collection in this area very difficult.

75. These are 1984 data on associate degrees and other occupational curriculums greater than 1 year, but less than 4 years. U.S. Department of Education, National Center for Education Statistics, *Digest of Education Statistics* (Washington, DC: 1987), p. 216.

76. Richard A. Ellis, "Engineering and Engineering Technology Enrollments, 1987," *Engineering Education*, October 1988, pp. 51-54, reports declining enrollments through the 1980s; and in the May 1988 issue (Ellis, op. cit., footnote, 74) a downturn in 4-year degrees for 1987. Lack of good definitions, poor institutional recordkeeping, the diversity and informality of many programs, and changes in survey methods and scope make it difficult to track trends. Lawrence J. Wolf, "The Emerging Identity of Engineering Technology," *Engineering Education* April/May 1987 p. 725, reports, based on National Center for Education Statistics data, that engineering technology bachelor's degrees (and associate programs) have been growing about twice as fast as engineering degrees.

Technologist education may be even more equipment-intensive than engineering education. Hands-on experience is a hallmark of successful programs. Simulation and computer graphics can help. There is a chronic need for instructional materials, access to facilities, and employers' giving time off. Many large companies offer extensive in-house training, but have difficulty in hiring people to do the training.

Better coordination of course content and requirements between curricula at 2- and 4-year institutions could make it more likely that academically-oriented technician or technologist students would be able to transfer to engineering programs.[78] There is nothing in the American educational system comparable to the institutions created in England, France, and Germany in the 19th century to provide mobility into engineering jobs for skilled workers lacking formal education. The tension between the shop culture of early American engineering (dominant through the 1800s) and the university culture of science-based engineering (dominant after World War II) has widened the gulf between engineers with degrees and knowledgeable workers without them. Skilled workers possess valuable expertise, but without a formal credential or professional license they are not considered "engineers."[79]

Although technologists and technicians have degrees, engineering culture reinforces the status differential. Some argue that many engineers are employed in industry in capacities that do not use their formal training well, in jobs that could filled by other

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77. H.R. 2134, *Congressional Record*, vol. 133, No. 62, Apr. 22, 1987.

78. An underlying issue is the content of the college-preparatory "academic" curriculum track in high school as opposed to the "vocational" track:

> - One of the most important and least understood segments of the education and training system is the set of institutions that provide vocational training. . . . The proportion of postsecondary students enrolled in vocational fields has increased notably, as have the number and variety of service providers. Yet little is known about the institutions and people that constitute the system of postsecondary vocational education, the reasons students enter and exit the system and, ultimately, the extent to which students benefit from the training they receive.

National Assessment of Vocational Education, *First Interim Report* (Washington, DC: January 1988), p. 6-1. Under the Perkins Vocational Education Act, high school vocational education serves a diverse clientele. Programs under the Comprehensive Employment and Training Act and Job Training Partnership Act are for different purposes and have not directly addressed the need for technicians. Warren Anderson, "Community Colleges and Technician Training," testimony before the House Subcommittee on Science, Research and Technology, Committee on Science and Technology Committee, Sept. 30, 1985, p. 231.

79. See, for example, National Society of Professional Engineers, "PE — A License for Success," *Engineering Times*, vol. 8, No. 3, May 1986, p. 4.

expert workers. The situation suggests that technicians and technologists could augment the ranks of engineers in times of high demand.[80]

ROLES OF THE FEDERAL GOVERNMENT

Industry dominates the engineering labor market. Universities generate the supply of new engineers. Together with the professional engineering community, industry, and academia have shaped engineering education. The Federal Government, although a major player, affects engineering education mainly indirectly, by supporting higher education and academic research, and by mounting major national R&D programs that drive industrial and academic demand for engineers. Federal R&D and student support programs can affect the distribution of engineers among fields and sectors, but most of this fine-tuning is overshadowed and overtaken by the effects of the labor market. The Federal Government has left most supply adjustments to the market.

This approach has worked fairly well, but periodic shortages of engineers bring calls for Federal "remedies," such as to produce more engineers in the specialties in vogue and to provide timely information on engineering labor markets. The rising cost of engineering research and education has drawn attention to Federal funding for university equipment, facilities, and institutional development. Federal actions have also been prompted by social concerns, such as access of minorities and women to engineering careers, and having sufficient personnel to work on high-priority Federal military, space, and public works R&D. Federal concern for a healthy supply of engineers has been boosted by the historically increasing Federal role in business and R&D, and pressure for coordinated national action to stimulate innovation and international industrial competitiveness.

About 8 percent of engineers work directly for the Federal Government or military, but far more engineering employment depends directly or indirectly on Federal R&D and procurement (largely defense-related).[81] Roughly 20 to 40 percent of engineers are employed in defense-supported work, most in industry and government.[82] On campus, military spending is a substantial amount of the support received by engineers: DoD is the source of research funds for one-quarter of academic engineers.[83] The rising DoD presence in Federal R&D spending worries some that the military will siphon engineers from industry and widen the gap between military and civilian skills. One recent report concluded, however, that military R&D spending increased demand for engineers, which in turn bolstered the supply and benefited all employers of engineers — civilian, academic, and military.[84]

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[80] This is why industry has adamantly not supported the hiring of only engineers with a P.E., and why continuing education for relicensure has never gained momentum. Industry can hire anyone it wants and call him or her an "engineer."

[81] National Science Foundation, *U.S. Scientists and Engineers: 1986*, NSF 87-322 (Washington, DC: U.S. Government Printing Office, 1988), p. 36.

[82] Ibid., p. 118, 124; and Michael Davey and Genevieve Knezo, Congressional Research Service, 1987, "The Federal Contribution to Basic Research: Background Material for

Graduate Education

There have been continuing shortages of Ph.D. engineers. A recent survey of engineering department heads reinforced the role of financial assistance in attracting graduate students (again see table 3-12 in the preceding chapter).[85]

Doctoral engineering programs grew rapidly after World War II, with the encouragement of the G.I. Bill, the National Defense Education Act, and large Federal research expenditures. Engineering Ph.D. awards rose from about 100 annually in the early 1940s to about 3,700 in the mid-1970s. The subsequent decline can be attributed to various factors: the end of the military draft, a ratcheting down of demand for engineering doctorates in industry and continuing strong employment of engineering baccalaureates, modest growth in academic hiring, and the waning attractiveness of academic posts when research money is tight (compared to the 1960s and 1970s) and teaching demands high (due to high undergraduate enrollments).

The early-1980s boom in undergraduate enrollments could swell the graduate population, but there is no sign of this yet and in the past there has not been a direct relationship between engineering B.S. awards and graduate enrollments. Some have predicted an increase in Ph.D. production approaching 4,000 Ph.D.s per year.[86] To achieve this, incentives for graduate study, and especially the redoubling of efforts to inform students about engineering opportunities, will have to improve (for an example, see box 4-E).

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[83] The Department of Energy supports 17 percent, much of that defense-related; the National Aeronautics and Space Administration and the National Science Foundation support 14 percent each. National Science Foundation, op. cit., footnote 81, p. 129.

[84] National Academy of Engineering, *The Impact of Defense Spending on Nondefense Engineering Labor Markets* (Washington, DC: National Academy Press, 1986), esp. Eli Ginzberg, "Scientific and Engineering Personnel: Lessons and Policy Directions," pp. 25-41.

[85] Faculty attitudes toward undergraduate engineering students is a "wild card": abundant anecdotes indicate that encouragement, along with increased graduate stipends, would make a difference. The College of Engineering at the University of Illinois-Urbana is a case in point.

[86] National Research Council, *Engineering Graduate Education and Research*

The Federal Government is the primary source of support in graduate school for less than 10 percent of U.S. engineers who earn Ph.D.s, and less than 5 percent of all Ph.D. engineers (see table 4-3).[87] Research assistantships are the most widespread funding source; they support nearly three-quarters of successful Ph.D.s and are primary support for over one-half of Ph.D.s. Loans supplement other funds for few students. Ph.D. engineers are twice as likely as Ph.D. scientists to have received support from industry or an employer (8 percent v. 4 percent in 1986), but industry's role is still quite small relative to university and Federal support.[88] A comparison of sources and types of support awarded to engineering and science graduate students in 1986 is presented in table 4-4.

From 1973 to 1983, graduate stipends fell from one-half to nearly one-quarter of rapidly rising starting salaries for B.S. engineers.[89] To lure engineering students away from high-paying industry jobs and into graduate school, many institutions have increased the amount of graduate student stipends, based on a rule of thumb of one-half of industry starting salaries (which approach $30,000 for B.S. engineers). The creation of industry-linked academic centers for engineering research (for example, NSF-supported Engineering Research Centers and the many anticipated local variations on them[90]) could enhance the attractiveness of academic careers more than simply increasing graduate stipends. More likely, academic centers will be a phase; like so many other proposed innovations, it will fade as a fashion or be absorbed into the academic culture of engineering.

Federally and State sponsored interdisciplinary engineering research centers and new university-industry institutions, such as the Engineering Research Centers, have been geared not only to R&D but also to education and manpower development.

(Washington, DC: 1985), p. 1.

[87] The proportion of graduate students with Federal support, as opposed to those who complete Ph.D.s, is 2 to 3 times higher.

[88] National Research Council, op. cit., footnote 36, p. 54.

[89] Jerrier A. Haddad, "Key Issues in U.S. Engineering Education," *The Bridge*, summer 1983, p. 12.

[90] Nam P. Suh, "The ERCs: What We Have Learned," *Engineering Education*, vol. 78, No. 1, October 1987, pp. 16-18.

Table 4-3. — Primary Source of Support, 1986 Engineering Ph.D.s
(in percent)

Source of Support	Engineering Sciences N=2,754[a]	Computer Sciences N=340[a]	All N=13,654[a]
Institutional[b]	68	58	54
Federal	6	4	11
Personal	16	26	30
Other[c]	10	12	6

[a] Number reporting source of support, about 90 percent of total Ph.D.s.
[b] Includes State.
[c] Includes corporate and foreign.

SOURCE: National Research Council, unpublished 1987 data.

Table 4-4. — Primary Sources and Types of Support of Engineering and Science Graduate Students, 1986
(in percent)

Type of primary support	Engineering	Science
Fellowship	8	9
Federal	1	2
Non-Federal	7	7
Traineeship	1	7
Federal	-	4
Non-Federal	1	2
Research assistantship	34	23
Federal	16	12
Non-Federal	18	11
Teaching assistantship	18	25
Federal	-	-
Non-Federal	18	25
Other	38	37
Federal	3	3
Non-Federal	35	35
Primary source of support		
Federal	21	19
Department of Defense	7	2
National Science Foundation	5	4
Other Federal	9	13
Institutional	33	44
Other	17	8
U.S.	13	6
Foreign	4	2
Self-support	29	29

NOTE: Full-time students in doctorate-granting institutions. Students in master's-granting institutions have a similar distribution of support: slightly more self-support, less Federal, and slightly less research assistantship support.

SOURCE: National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1986*, NSF 88-307 (Washington, DC: 1988), pp. 49-50, 153-167.

Education goals are to bring students into contact with industry personnel and R&D problems and, in some cases, develop new engineering curricula.[91] Little is known as yet of the impacts of such centers on education, in part because NSF eschewed evaluation efforts from the start. Congress continues to monitor the educational activities of industry-university centers.[92]

About 150 universities offer engineering Ph.D.s.; many award only a few each year. Thirty institutions produce nearly two-thirds of engineering Ph.D.s. These same institutions receive a large share of Federal R&D funds. The National Research Council concluded that the existing institutions could expand production significantly without creating new Ph.D. programs, and that building on the existing base of faculty, equipment, and facilities would be most cost-effective.[93]

The engineering doctorate mixes two philosophies. Industry still dominates employment of Ph.D.s, but the research-oriented science model guides engineering graduate study — inappropriately, some claim.[94] The deterioration of U.S. competitiveness has called into question the value to industry of this academic model, entrenched during the 1960s' explosive growth of Federal research funding, graduate student support, and doctoral enrollments. Many engineering faculty who earned doctorates during the 1960s and 1970s, so the argument goes, have lacked appreciation for the relation of engineering to industrial production. This faculty bias is said to promote a neglect of design in undergraduate engineering coursework and a failure to relate engineering solutions to the creation of manufacturable and marketable products. Given the strong symbiosis between engineering education and industry, this issue is now receiving renewed attention.[95]

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91. Edmund T. Cranch, Department of Defense and Carnegie-Mellon's Software Engineering Institute, "Continuing Education in the United States," *Engineering Education*, April/May 1987, p. 663.

92. See U.S. Congress, General Accounting Office, *Engineering Research Centers: NSF Program Management and Industry Sponsorship*, GAO/RCED-88-177 (Washington, DC: 1988).

93. National Research Council, op. cit., footnote 86, p. 85.

94. See Edwin T. Layton, "Science as a Form of Action: The Role of the Engineering Sciences," *Technology and Culture*, vol. 29, January 1988, pp. 82-103.

95. American Society for Engineering Education, *A National Action Agenda for Engineering Education* (Washington, DC: 1987), pp. 15-17. Also see National Research Council, *Engineering Personnel Data Needs for the 1990s* (Washington, DC: National Academy Press, 1988).

For example, poor management of manufacturing has been offered as the reason for the United States failure to take commercial advantage of home-grown technological developments. Ignoring manufacturing and relegation of manufacturing technology to technical schools is seen as catastrophic not only for mechanical engineering, but also for American manufacturing in general.[96] Compared to other engineering specialists, manufacturing engineers earn the lowest median income. Only a handful of U.S. institutions grant degrees in manufacturing engineering or systems. If the definition is broadened to include programs in computer-aided manufacturing, automation, materials, processes, robotics, and production, one-fifth of the 221 institutions listed in the ASEE 1986 *Directory of Engineering College Research and Graduate Study* qualify. This measure, while crude, suggests the lack of emphasis placed on manufacturing by U.S. universities and engineering institutes.[97] As one antidote, the National Institute of Standards and Technology is establishing technology centers at three eastern colleges, two (at Rensselaer Polytechnic Institute and Cleveland's Cuyahoga Community College) will be devoted expressly to manufacturing technology.[98]

CONCLUSION

The view persists that the future supply of engineers is directly related to technological innovation and the competitiveness of industrial production. Technology studies scholars, however, generally agree that managerial decisionmaking dominates the innovation process and that competitiveness is determined by a wide range of corporate, political, and social policy decisions that distance innovation and competitiveness from engineering education.[99] The engineering curriculum will continue to reflect the tension between longer-term academic priorities and shorter-term industrial needs. While there is no consensus on the "best" engineering curriculum, salutary features include communication between university and industry, work experience, hands-on laboratory

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96. National Academy of Engineering, *Education for the Manufacturing World of the Future* (Washington, DC: National Academy Press, 1985); and Reuel Shinnar, "The Crisis in Chemical Engineering," *The Bent of Tau Beta Pi*, fall 1987, p. 20.
97. W.J. Fabrycky et al., "Engineering College Research & Graduate Study: A 20-Year Statistical Analysis," *Engineering Education*, vol. 76, No. 6, March 1986, pp. 326-340.
98. See Will Lepkowski, "NIST Launches Technology Centers," *Chemical and Engineering News*, Jan. 9, 1989, p. 26.
99. Goldman, op. cit., footnote 67. For a bilateral dialogue on approaches to engineering education, see Edward E. David and Takahi Mukaibo, *Engineering Education: United States and Japan*, Proceedings of the Fourth U.S.-Japan Science Policy Seminar, Oct. 19-23, 1986, Honolulu, Hawaii (Washington, DC: National Science Foundation, 1988).

experience, and ongoing scrutiny by the academic and professional engineering communities.[100] Engineering education will not "save" the Nation or restore its economic vibrancy; it can, however, give a competitive edge to America's technology base.

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[100] Joseph Bordogna et al., "Linking Management and Technology — A Decade's Experience," *Engineering Education*, vol. 78, October 1987, pp. 23-28. Also see Edward Wenk, Jr., "Portents for Reform in Engineering Curricula," *Engineering Education*, vol. 78, November 1988, pp. 99-102; and Hans Mark and Larry Carver, "Educating Engineers for Leadership: The Fourth Revolution," *Engineering Education*, vol. 78, November 1988, pp. 104-108.

Box 4-A. — Perennial Issues in Engineering Education

Many engineering education issues center around the often conflicting priorities of academia, industry, and government as employers of engineers.[1] These conflicts are by nature irreconcilable, so that engineering education is likely to be a continuing arena of debate and its curriculum a continuing compromise between its many clients.

Current calls for reform of engineering education are only the latest among many from a community that has been extraordinarily self-conscious about its responsibility to students and its contributions to the economic vitality of the Nation. Since 1985 alone, the engineering community has called attention to the tension between education and practice, the measurement of quality, the National Science Foundation's Engineering Research Centers, and the impact of foreign graduate students on engineering education and employment.[2]

The roots of these concerns run deep. An OTA review of all major reports on engineering education, from the 19th-century birth of the profession through 1987, revealed a number of themes and perennial controversies that have defied easy resolution:[3]

- **Curriculum**

  The extent to which the undergraduate engineering curriculum should provide a general education or employment-guided training, and the extent to which industry's short-term needs should shape engineering education.

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[1] Robert Perrucci and Joel E. Gerstl, *Profession Without Community* (New York, NY: Random House, 1969); Edwin Layton, Jr., *The Revolt of the Engineers: Social Responsibility and the American Engineering Profession* (Baltimore, MD: The Johns Hopkins University Press, 1969); David F. Noble, *America by Design: Science, Technology and the Rise of Corporate Capitalism* (New York, NY: Knopf, 1985); and Lawrence P. Grayson, "A Brief History of Engineering Education in the United States," *Journal of Engineering Education*, December 1977, pp. 246-264.

[2] W. Edward Lear, *The Quality of Engineering Education Programs* (Washington, DC: American Society for Engineering Education, 1986); Don E. Kash, *The Engineering Research Centers: Leaders in Change* (Washington, DC: National Academy Press, 1987); and Elinor G. Barber and Robert P. Morgan, "The Impact of Foreign Graduate Students on Engineering Education," *Science*, vol. 236, Apr. 13, 1987, pp. 33-37.

[3] Steven L. Goldman, "The History of Engineering Education: Perennial Issues in the Supply and Training of Talent," OTA contractor report, 1987.

Distinguishing between engineering practice and science, and balancing the curriculum a) between more "theoretical" courses in mathematics and physical science and "practical" engineering courses, and b) between generic engineering science courses and specialized courses.

- **Faculty**

  The appropriate qualifications for engineering faculty in the "real world" practice of engineering, and the extent to which industry experience, in addition to a university Ph.D., is a desirable and sufficient credential for a faculty post.

- **Credentials**

  A 4-year v. a 5-year "undergraduate" program. The difficulty of preparing for a career and responding to a large and rapidly changing knowledge base in a 4-year B.S. program raises the issue of adding at least 1 more year, making the a 5-year B.S. or M.S. the first professional degree in engineering. However, 4-year programs are attractive to students, who can move into high-paying jobs, encouraged by a volatile, technology-responsive labor market.

  The proper role of government licensing and certification by an engineering professional society, in addition to job performance, as determining membership in the professional engineering community.

  The proper role and education of technicians, technologists, and paraprofessional engineers.

- **Careers and Continuing Education**

  Encouraging continuing education and professional development for engineers, including engineering faculty, and balancing this with the preference of some employers to invest in cheaper, younger, fresher engineers.

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Balancing engineers' responsibilities to employers, and building into engineering practice explicit recognition of the social impacts of technological innovation and the value-laden character of engineering judgment.

Box 4-B. — Expanding the Engineering Pool: Recommendations of the Engineering Deans Council

To attract more able students, to provide a more supportive environment, and to make engineering education more accessible, engineering educators should:[1]

Improve undergraduate recruitment and retention, especially of women and minorities

- Support and publicize intervention programs tailored for women and minorities through institutional consortia.
- Improve guidance materials.
- Strengthen elementary and secondary mathematics and science education.
- Coordinate curricula and counseling with community colleges to increase transfer to 4-year colleges, especially for women and minorities.
- Encourage dual-degree and transfer programs with liberal arts colleges.
- Keep better data on educational and career paths, especially retention rates.
- Implement lessons from successful intervention programs which improve the academic performance and retention of engineering undergraduates, especially women and minorities. In particular, support:
    - extended programs which allow students to proceed at a slower pace;
    - ambience that encourages nurturing, not weeding out;
    - orientation and transition programs for entering freshmen;
    - engineering student organizations; and
    - effective academic advising.
- Ensure that faculty are sensitive to the special needs of women and minorities.
- Establish specific goals, such as doubling the number of women enrolled by the end of the decade.

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[1] Based on Report of the Task Force on the Engineering Student Pipeline, "Findings & Recommendations," *Engineering Education*, vol. 78, May 1988, pp. 778-780.

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- Support programs to help women re-enter engineering after career interruptions.

Increase graduate enrollments

- Establish recruitment and retention goals for minority students.
- Sharpen recruiting of U.S. engineering graduate students, by:
  - actively targeting and recruiting promising undergraduates;
  - encouraging undergraduates to do research;
  - developing ties between graduate schools and undergraduate institutions with large minority enrollments;
  - opening engineering graduate study to nonengineering undergraduates;
  - publishing a guide to graduate programs; and
  - creating a listing in which graduate students and schools can find each other.
- Adjust graduate student stipends to at least one-half the starting salary for a B.S. engineer.
- Double the number of graduate fellowships available.
- Restore the tax deductibility of both tuition remission and graduate student stipends.

Box 4-C. — The Minority Introduction to Engineering Program (MITE)

The MITE program encourages high school students to enter and stay in engineering. MITE students gain confidence in science and engineering, are more likely to change their high school curriculum to prepare for college and technical majors, and are more likely to enter and stay in science and engineering majors in college than their peers.[1] Funding for MITE, like most other such programs, comes primarily from large corporations and corporate foundations.

MITE students are exposed to a college environment and "real" engineering in summer university-based programs. Each summer about 1,000 to 3,000 MITE students spend 1 to 8 weeks in programs at various engineering institutions. The typical program is 2 weeks, the typical student a Black male between junior and senior year in high school. The students tend to be high achievers, college- and engineering-oriented, and from a privileged socioeconomic and education background. Program content varies widely, as does the makeup of student groups.

Student alumni report favorable changes in high school courses, plans for college (70 to 80 percent apply) and planned major (70 to 90 percent engineering), impressions of the MITE program, and the impact of the program on their college and field decisions. MITE participants have a much lower first-year attrition rate than other minority engineering students.

Several 5-year followups all bear positive news on college attendance, major, jobs, post-graduation plans, financial aid, and the impact of the MITE program.[2] Almost all ex-MITE students are in college, most are in science or engineering majors, and many plan graduate study. Women especially are encouraged by participation in MITE. About one-half of the students attend the college where they did their MITE program.

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[1] MITE began in 1974. Since 1975 MITE has conducted evaluations, based on annual and 5-year followup surveys. Survey results are incomplete and nonrepresentative. UNITE, a separate military extension of MITE, is not included in this discussion. Both are creations of JETS, the Junior Engineering Technical Society.

[2] Conducted by the Accreditation Board for Engineering and Technology. Response rates have been 15-20 percent.

MITE is drawing on students who are already interested in engineering in college. Three-quarters of the students going into MITE already prefer engineering; 80 percent coming out do.

Box 4-D. — The National Technological University

The National Technological University (NTU), based in Fort Collins, Colorado, offers specially developed science and engineering courses by satellite communications to technical staff at corporate and educational centers. Technical professionals can thus keep their skills up-to-date without the disruption and expense of leaves of absence. Twenty-eight universities and 60 sponsoring corporations and government agencies nominate students for NTU coursework.[1]

NTU encourages its sponsors to create courses, spreading the very considerable cost of development over a much larger base than that available to any single institution. The amortized cost of development, distribution, and electronic distribution allows a great variety of specialized courses to be developed and offered on very flexible schedules.[2]

In general, corporate education programs reflect greater educational efficiency than schools and colleges. They spend far more time and money on evaluating and experimenting with different teaching and learning formats. They are, therefore, a potentially valuable resource for colleges implementing educational technologies and techniques about which industry may already have accumulated a great deal of data. The Federal Government, a subscriber to NTU, also supports research and experimentation.

NTU is not the only one of its kind, although it is by far the largest and has absorbed many smaller systems. One-way education video, with audio teleconferencing, expanded from a single system in 1964 to over 40 systems in 1986, serving over 50,000 engineers and other technical professionals. The phrase, the "televersity," has been applied to the NTU phenomenon.[3] General trends driving greater use of televised, computerized, and distance education are:

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[1] James Krieger, "Management-of-Technology Program Debuts," *Chemical & Engineering News*, Jan. 16, 1989, p. 34. Six M.S. programs are now offered: computer engineering, computer science, electrical engineering, engineering management, manufacturing systems engineering, and the newest offering in management of technology.

[2] Most National Technological University (NTU) courses originate in member universities, and a few in industry. There were about 120 sites in the fall of 1987; two channels broadcast 18 hours a day. In 1987 NTU offered 120 courses, with 4,000 hours of graduate credit instruction. This remote learning seems to be as effective as traditional classroom instruction. *NTU News*, vol. 3, No. 4, November 1987.

- the high and rising proportion of students who are employed and studying part time;
- technical improvements;
- cost decreases and economies of scale as more users get on the systems;
- the high cost of release time and commuting time for employees to take courses in traditional classrooms;
- the higher demand for continuing technical education to maintain work force competence and improve productivity;
- employee and union interest in continuing education; pressure for education as employee benefits; worker satisfaction;
- market pressure on universities to find new sources of revenue and new services to provide; and
- the rise of non-university educational providers.

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[3] Thomas L. Martin, Jr., *The Televersity: The University of the Future* (Surrey, England: Industry and Higher Education, September 1987).

Box 4-E. — National Consortium for Graduate Degrees for Minorities in Engineering, Inc. (GEM)

GEM sponsors about 100 to 160 students a year in master's and doctorate engineering study. Since GEM's founding in 1976, 12 percent of minorities holding graduate engineering degrees have been sponsored by GEM.[1]

The director of the program, Howard G. Adams, cites the heavy recruiting and high salaries offered by industry as a major reason that minorities do not go on for graduate engineering education. Other reasons include the perception that an advanced engineering degree is worth little in terms of career or salary, ignorance of the availability and process of financing graduate study, and competition from other majors such as business and law.[2] In addition, students face institutional barriers, GRE scores, poor academic preparation. Adams offers four recommendations for institutions:[3]

- intensify efforts to identify and recruit full-time minority graduate students with undergraduate research assistantships, open houses and career days, participation by minority faculty and students (especially in recruitment at minority colleges), and publicity materials that target minorities;
- revise criteria for admissions by considering qualitative information such as motivation and work experience, explain how admissions works, and make sure that admissions criteria are appropriate for student success;
- provide financial support, ensure its equitable distribution, and use teaching and research assistantships to foster faculty-student interaction; and
- make sure the academic environment involves and supports minorities in teaching and research apprenticeships, seminars, publishing and presentations, and advising.

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[1] *Manpower Comments*, vol. 25, No. 3, April 1988, p. 17.

[2] Howard G. Adams, "Advanced Degrees for Minority Students in Engineering," *Engineering Education*, vol. 78, May 1988, pp. 775-777.

[3] Ibid., p. 777.

Appendix A.—The Mathematics Workshop Project: Intervention With a Difference at the University of California, Berkeley

The Mathematics Workshop Project was created by Uri Treisman as a component of the University of California, Berkeley's Professional Development Program (PDP).[1] Since 1978, Black and Hispanic undergraduates in this honors program have earned higher mean grades in calculus at Berkeley than nonworkshop minority students and have graduated from the university at rates roughly comparable to those of white and Asian students. The program was created in response to concerns about the low achievement among Black undergraduates at Berkeley in mathematics, but its unique format grew out of research undertaken by Treisman to explain why Blacks were having such intense problems in their adjustment to university life.

Treisman sought to answer not "Why do Blacks do so badly in mathematics?" but rather, "Why are Chinese students so successful in a subject that non-Chinese minority students find so daunting?" He assumed, quite plausibly, that Blacks might enjoy the same levels of success of the Chinese if a means to promote successful study habits and a productive approach to mathematics could be determined.

For many years, these two groups have been at very different points in the academic pecking order at Berkeley: Chinese students have traditionally been the most accomplished mathematics students at the university, while Blacks have been the least accomplished. For example, in 1975 only 2 of the 21 Black students who enrolled in the first course of the three-term calculus sequence managed to complete the last term in the sequence with a grade higher than "C." Since calculus is required for most of the academic majors that minority students at Berkeley pursue (e.g., architecture/ environmental design, business, engineering, natural sciences, and premedicine), this pattern of failure for Blacks has had devastating consequences for their academic persistence and graduation.

In 1975 Treisman first interviewed 20 Black and 20 Chinese students about their study habits and their methods of preparing for examinations. He subsequently observed them around the clock — in their homes, on dates, as they interacted with family and friends — for almost 18 months to obtain some sense of how their adjustment to campus life and to the study of mathematics differed.

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[1] This appendix is based on Robert Fullilove, "Images of Science: Factors Affecting the Choice of Science as a Career," OTA contractor report, 1987, and especially on an interview of Treisman who elaborated on the origins of his work. Treisman's approach to the creation of programs for minority students in mathematics is featured here.

Among Black students he found a pattern of cultural, social, and academic isolation. Many of these students had come from high schools where few students attended college. They had achieved success in secondary mathematics by becoming extremely self-reliant and by becoming relatively isolated from the social life pursued by other students. At the university these habits of isolation — studying long hours alone, resisting the temptation to hang out with friends — persisted. Unfortunately, such patterns proved harmful to their adjustment to the university: most of these students became lost and confused by the blistering pace of first-semester calculus. They were unwilling to seek help from other students or from many of the remedial programs created to assist minority students. They saw these programs as having been created for poorly prepared, weak students, and their pride simply would not permit them to admit to others that they were struggling. Thus:

> The freshman year at Berkeley was a time of rude awakening and disorienting surprises, even for many black students who had attended academically reputable, predominantly white high schools. Even though these students were relatively well-prepared academically, the pace and intensity of competitive first-year mathematics and science courses coupled with the unexpected social isolation they encountered prevented many of them from getting their bearings or developing adequate study habits; thus, few did well in their courses.[2]

The 20 Chinese students in his study, by contrast, almost immediately upon their matriculation at the university, found friends and classmates with whom they studied regularly. Twelve of the 20 formed informal study groups that became a vehicle for mastering mathematics and for becoming acquainted with life in the university.

> Composed of students with shared purpose, the informal study groups of Chinese freshmen enabled their members not only to share mathematical knowledge but also to "check out" their understanding of what was being required of them by their professors and, more generally, by the University. These students learned quickly, for example, that the often-quoted rule of thumb for estimating the number of hours that one should devote to study — two hours for each class hour — was seriously

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[2] Philip Uri Treisman, University of California, Berkeley, "A Study of the Mathematics Achievement of Black Students at the University of California, Berkeley," doctoral dissertation, 1985, p. 22.

> misleading. The blacks whom I had interviewed devoted approximately eight hours per week to homework and study for their four-unit math course; the Chinese devoted roughly fourteen hours per week to these same tasks.[3]

Treisman was particularly struck by the efficiency with which Chinese students within these groups mastered critical concepts in the course, concepts that, by contrast, left many of the Black students in his study bewildered. Black students, Treisman observed, were frequently stumped by a problem whose solution consumed hours of their time — often without success.

The Chinese students, when confronted with a similar problem, were quickly able to consult others in their study group. Typically, if no one in the group had come up with a solution, group members concluded that the problem was difficult enough and significant enough to warrant consulting the teaching assistant (TA) for help. Black students, by contrast, almost never sought out such assistance, particularly from the TA, because they were fearful that they would be exposing a weakness.

It became apparent to Treisman that group study offered many options that would be particularly useful to Black students at the university. First, study groups would provide an efficient vehicle for mastering the challenges of calculus. The interaction of students as they struggled with difficult, challenging problems appeared to have clear benefit for students who were prone to getting stuck. Second, study groups would provide students with an opportunity to combine their social and academic lives, and in so doing, combat much of the social isolation that Treisman had observed among the Black students in his study.

In order to avoid the appearance of being "just another remedial program," Treisman and the staff of the Professional Development Program billed their Mathematics Workshop program as an honors program. The "honors" label was not difficult to sell. PDP is sponsored by the University's Academic Senate under the auspices of a standing committee of the Senate, the Special Scholarships Committee. Created in 1964 this committee has counted some of the university's finest scholars (including two Nobel prize winners) among its members. Having such a committee sponsor an honors program, therefore, was consistent with student expectations of how the university functions.

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[3] Ibid., p. 13.

The workshop's honors focus was not meant to suggest that its participants were selected because of their superior academic credentials; rather, the workshops would require that each student strive to earn honors-level grades as a condition of his or her participation. One clearcut benefit has been derived from this emphasis. The workshops attract highly-motivated students who see a direct relationship between working for high grades and achieving their career or graduate school objectives. Thus since the creation of the Mathematics Workshops, PDP students typically put twice as much time into studying each night as is suggested by conventional campus wisdom. This increased "time-on-task" is believed to explain, in part at least, why workshop students do so well.

The work that students are asked to complete in each workshop is intended to be of a more formal nature than the work Treisman observed among the study groups of the Chinese students in his study. However, the basic principles that made these informal groups so successful — the intense discussion and debate between students around difficult problems in mathematics — were retained and elaborated on. These features remain a distinct component of the program today.

The current version of the program centers around workshops that enroll approximately 20 to 25 students each. Each workshop meets for 2 hours twice a week. Each workshop session consists of both individual and group work that is centered on the problems contained in a "worksheet." Worksheet problems typically include:

> (1) old chestnuts that appear frequently on examinations but rarely on homework assignments; (2) monkey wrenches — problems designed to reveal deficiencies either in students' mathematical backgrounds or in their understanding of basic course concept; (3) problems that introduce examples or counterexamples to shed light on, or delimit, major course concepts or theorems; (4) problems designed to deepen the student's understanding of and facility with mathematical language; and (5) problems designed to help students master what, in workshop parlance, is known as "street mathematics" — the computational tricks and shortcuts known to many of the best students, but which are neither mentioned in the textbook nor taught explicitly by the instructor.[4]

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[4] Ibid., pp. 42-43.

Students work on these problems alone at first, then together in a group of four or five other students, all of whom have been working with the same problems. The major objective of the group work is to have students communicate with others about their efforts to develop solutions. This communication may be facilitated in a number of ways: 1) students may be asked to present their problem solutions to others in their group (or if the situation warrants it, to the entire workshop); 2) two or three students may be asked to edit another student's work, paying particular attention to issues of mathematical accuracy (e.g., was the correct form followed?), and to the elegance and clarity of the student's conclusions; and 3) students who appear to be well advanced in their work may be asked to tutor slower students until everyone in the group has arrived at the same level of expertise.

The advantage of these approaches is that the art of communicating complex ideas and concepts is an important means through which students organize and clarify their thoughts. As Treisman observes: "By continually explaining their ideas to others, students acquire the same benefits of increased understanding that teachers themselves regularly experience." If students find it difficult to express themselves, they become immediately aware of the inconsistencies in their understanding. Moreover, their efforts to make themselves understood — particularly in the face of pointed, thoughtful probing by the listeners — may also lead them to explore facets of a particular concept that might not otherwise have occurred to them. Discussing the solutions to worksheet problems also provides students with an opportunity to practice the skills and to exhibit the mastery of course concepts that they are expected to demonstate on quizzes and examinations.

Students are not alone in the workshops, however. A workshop leader — typically a graduate student in mathematics or physics or some other similarly quantitative field — will be responsible for the preparation of the worksheets and for directing the activities of workshop students. Leaders are taught to be unobtrusive. Their major task is to ensure that students are communicating effectively about the work at hand.

> Towards these ends, the leader circulates among the students and listens carefully to their discussions. When he suspects that students are not listening carefully to one another, he intercedes, perhaps asking a student to restate something he has said more precisely or to explain in more detail the steps by which he arrived at the solution to a certain problem.[5]

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5. Ibid., pp. 44-45.

One clearcut advantage of the group study format used in the workshop is that anyone listening to the conversations students are having about their work has a unique glimpse of the mathematical thought processes of each of the speakers. As students discuss their struggles with the material, they are literally making their problem solving algorithms public. At the same time, these conversations provide the workshop leader with numerous opportunities to determine the degree to which students have mastered important material and key ideas. If students are unclear about the work, their problems will quickly become obvious.

The workshop, therefore, is an ideal instructional setting: it offers students an opportunity to practice the skills they will be expected to demonstrate in quizzes and examinations; it forces students to communicate with each other in a fashion that promotes greater mastery of difficult concepts as well as familiarity with the language and syntax of mathematics; and finally, it provides instructors with a vehicle for monitoring the progress of students as they master course materials.

Data on student achievement suggest that the program has been extremely successful:

- Black students at Berkeley are at greater risk of academic failure and are more prone to leave college before graduation than any comparable group of students. Significantly, 55 percent of the 231 Black students who were enrolled in the workshop program between 1978 and 1985 earned grades of "B-" or better in calculus; only 21 percent of the 284 nonworkshop Black students who took calculus during this period earned comparable grades. The mean final calculus grade for workshop students was 2.6 (N=231); the comparable mean for nonworkshop Blacks was 1.9 (N=284).

- The workshops also had a dramatic impact on student failure in mathematics: during the period between 1978-85, only 8 Black workshop students in 231 (3 percent) failed calculus; by comparison, 105 of 284 (37 percent) nonworkshop Black students failed the course.

- Perhaps the most significant impact of the workshops was on the mathematics achievement of poorly prepared students — those who entered the university with SAT mathematics scores in the lowest tercile (200 to 460) of the score distribution. The mean final grade in calculus for Black workshop students with poor mathematics preparation (2.2; n=56) was four-tenths of a grade point higher than that of nonworkshop Black students (1.9; n=42) with "strong preparation" in mathematics (defined as students with an SAT math score above 550).

- Participation in the workshops was also associated with high retention and graduation rates. Approximately 65 percent of all Black workshop students who entered the university in 1978 and 1979 (47/72) had graduated or were still enrolled in the spring semester of 1985. The comparable rate for nonworkshop Black students entering the university in those same years was 47 percent (132/281). The proportion of workshop students earning degrees in science and/or mathematics-related fields was 44 percent — the comparable rate among nonworkshop students was 10 percent. Comparable rates of achievement and persistence have been reported for Hispanic workshop students as well.

Treisman's success with this approach extends beyond the boundaries of the Berkeley campus. Successful adapations of the workshop program — defined as programs whose Black and Hispanic students have earned final mean grades in calculus of 2.7 or better — have been created at the University of California-Los Angeles, University of California-San Diego, University of California-Santa Cruz, and California State Polytechnic University-Pomona. Similar secondary-level adaptations have been created for high school students in Albany, Richmond, Stockton, and Orange County, California.

These adaptations are by no means exact clones of the Mathematics Workshop program at Berkeley, but they all share key features. Treisman stresses that at the college level there is much to be learned by studying successful students. Successful students typically have a "bag of tricks" for dealing with institutional bureaucracies (e.g., how to navigate the financial aid mess, how to locate helpful TAs, how to approach faculty members if you have a "dumb" question), as well as useful strategies for succeeding academically (e.g., which campus classrooms are open all night, which questions always appear on so-and-so's examinations). Where possible, these pieces of received wisdom need to be incorporated into the design of programs that serve students at all educational levels and should be integrated into the academic and personal advising that students are given by program staff. In Treisman's words:

> What should not be overlooked here is the fact that every minority student who gets an "A" in a mathematics course that other equally (or better) prepared students failed may have learned something that we should pass on to others. Too much educational research concentrates on explaining the variance in performance when, in reality, it is the unexplained variance — typified by the kids whose success can't be explained by race, SES, prior levels of preparation for mathematics, or time-spent-on-task — that may hold the answer to some of our knotty questions about how to design programs that promote student success.

Treisman goes on to note that the most successful teaching techniques are those that attempt to have students approach mathematics the way mathematicians do, by looking for and examining patterns. In too many instances, mathematics instruction fails to provide students with an opportunity to explore mathematics or to play with the patterns that fascinate and entrance mathematicians.[6] Instead, the curriculum concentrates on rote procedures and on getting the right answer. "Students are taught, in other words, to focus on one of the end products of mathematics — the answer — and not on the potentially fascinating process we engage in to generate that answer."

In the Stockton Summer Math Institute, a project that Treisman directed in 1987, with support from the Hitachi Foundation, the search for pattern was placed at the core of the curriculum of a summer program for ninth graders. In one of the courses offered, students were introduced to variables as "pattern generalizers" and were given an opportunity to use variables to understand arithmetic progressions.

Not surprisingly, the program involves working with interesting problems and working in small groups of the type used in PDP's Mathematics Workshops. Preliminary reports of the achievement of Stockton Summer students, the majority of whom were minority students, strongly suggests that there is considerable merit to this approach. At the beginning of the program, the mean percentile score of participating students on a test of mathematical problem solving skills was 27; at the end of the program the mean was 78. Student attendance and morale were described as "excellent," and observers feel that the model has tremendous potential as a tool for assisting students to make a successful transition from middle school mathematics to the college-track algebra course in high school.

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[6] In this vein, see Lynn Arthur Steen, "Out From Underachievement," *Issues in Science & Technology*, vol. 5, fall 1988, pp. 88-93.

Treisman's final observation is related to teachers and their role in mathematics instruction. He points out that in all too many schools with predominantly minority enrollments, mathematics is taught by teachers who are not trained for it and who may have been assigned teaching duties in the subject against their will. Efforts to reform teaching techniques and the content of the curriculum pass these teachers by because they have neither the time, the opportunity, nor the interest in learning how to teach the subject well. If change is to occur, a number of important alterations must be made in the way we try to affect how teachers teach mathematics.

The Stockton Summer Math Institute provides key insights to the nature of these changes. Teachers who participated in the institute were actively involved in the development of the institute's curriculum and in the preparation of teaching materials. In many teacher training programs, teachers are treated as "students": they become passive learners who have little or no opportunity to bring their own classroom expertise to bear as they learn new techniques and ideas.

Stockton Institute teachers, however, adapted the materials they would use in the classroom from a variety of texts and teaching materials, guided in large part by their own sense of what they knew to be effective methods for presenting topics to their students. If curriculum materials are developed on the assumption that they should be "teacher proof" — that is, able to be used without any direct involvement of the teacher — is it any wonder that teachers ignore them?

From these experiences, Treisman concludes: 1) mathematics is something that students must do, not as a set of rules that they must memorize, but rather as an activity in which they must be actively engaged; and 2) instruction works best when students are given an opportunity to communicate with each other about their work and when teachers are in a position to observe, and, where necessary, intervene, in that communication.

Treisman is a mathematician first and a teacher second. His philosophy of teaching reflects a desire to provide students with opportunities to do the things that mathematicians do, to search for and examine patterns. One sees in the PDP programs a greater concern with the process of doing mathematics — designing classroom opportunities to observe what students are doing with mathematics problems — and less focus on the products of students' labors — i.e., the answers. There is a concern with maximizing opportunities for teachers to observe students at work, doing the kinds of problems and exercises that elicit the skills and abilities we are most interested in having students acquire. Finally, group work has the potential to influence the dynamics of peer groups within the schools. At present, in all too many schools, academic achievement, particularly in mathematics and science, is not valued by students.

Finally, and most significantly perhaps, Treisman's work helps to place much of the research in mathematics education in some much needed perspective. Much research has focused on the structural barriers (both personal and systemic) that inhibit (or promote) student success in science and mathematics courses. What has been suggested here is: 1) that students succeed when the proper conditions for success are provided; and 2) that we do, in fact, know something about what those conditions must be. The key to students' success, Treisman has noted, is not the student's "native ability" for mathematics, but rather the institutional ability to design instructional settings that promote excellence. Workshops students, Treisman is fond of saying, provide an "existence proof" — they demonstrate how much can be achieved if the proper conditions are created and maintained. They also demonstrate that mathematics excellence can be achieved by minority students if it is demanded of them.[7]

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[7] A fitting postscript is that in June 1988 the Charles A. Dana Foundation awarded $737,000 to the University of California, Berkeley to establish a center to assist other colleges in educating minority students in mathematics and science. In Treisman's words: "The Dana Award [for Pioneering Achievement in Higher Education] legitimized our work." See Liz McMillen, "Dana Awards for Undergraduate Education and Health Prompt Debate on the Proper Role of Foundations," *The Chronical of Higher Education*, Nov. 2, 1988, p. A-28-30. While honoring individuals, such awards dramatically raise the visibility of issues and allow for the replication of a successful program like the Mathematics Workshop Project on many other campuses.

Appendix B.—Productivity Ratios for the Leading 100 Undergraduate Sources of Science and Engineering Ph.D.s

One way to investigate the effect of undergraduate settings on science and engineering careers is to look at what types of undergraduate institutions produce the most people who go on to get science and engineering Ph.D.s. OTA conducted an analysis of institutions' "productivity" of science and engineering Ph.D.s, and also looked at trends in this institutional productivity over time. OTA analyzed this productivity at six points in time, looking at baccalaureates conferred between 1951 and 1976.[1] Trends in science and engineering Ph.D. awards, lagged from the mid-1950s to 1986, yield measures of institutional Ph.D. "productivity" in terms of baccalaureates going on to earn science and engineering Ph.D.s.

A way of looking at institutional productivity, independently of institutional size, is to look at the proportion, rather than the absolute numbers of baccalaureate graduates who go on to earn science and engineering Ph.D.s. The "productivity ratio" for each institution was calculated by dividing the number of baccalaureates from institution "A" that went on to earn a science/engineering Ph.D. from any doctoral granting institution for a specific referenced baccalaureate year (or for the total of the 6 referenced baccalaureate years) by the total number of baccalaureates awarded by institution "A" for the same referenced year(s). The baccalaureate year was used as the reference point, rather than the Ph.D. year. For example, the number of baccalaureates who graduated from the Massachusetts Institute of Technology (MIT) in 1955-56 and continued graduate studies to earn a science and engineering Ph.D. (irrespective of where and when said Ph.D. was earned) was divided by the total number of baccalaureate degrees awarded by MIT in 1955-56.

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[1] Betty D. Maxfield, "Institutional Productivity: The Undergraduate Origins of Science and Engineering Ph.D.s," OTA contractor report, July 1987, table 1A. Six academic years were sampled for baccalaureate data: 1950, 1955, 1960, 1965, 1970, and 1975.

Leading 100 Undergraduate Sources of Science/Engineering Ph.D.'s for 6 Selected Years

(Adjusted for Institution Size)

Rank	B.A. to Ph.D. rank	Institution	Total # S/E Ph.D.'s	Productivity ratio	Type
1	32	Cal Institute of Technology	388	44.34	Private
2	207	Harvey Mudd College/CA	68	30.63	Private
3	2	Mass Institute of Technology	1,114	21.28	Private
4	104	Reed College/OR	172	20.67	Private
5	78	Swarthmore College/PA	228	17.14	Private
6	146	Cooper Union/NY	126	13.71	Private
7	23	Chicago, Univ of/IL	497	13.48	Private
8	154	Radcliffe College/MA	97	13.43	Private
9	51	Rice University/TX	288	11.98	Private
10	179	Haverford College/PA	86	11.73	Private
11	453	New Coll-South FL U	30	11.63	Private
12	111	Carleton College/MN	161	10.95	Private
13	108	Pomona College/CA	161	10.16	Private
14	159	Grinnell College/IA	119	9.87	Private
15	50	Oberlin College/OH	292	9.72	Private
16	131	Antioch College/OH	156	9.41	Private
17	112	Calif, U-San Diego	127	9.37	Public
18	5	Cornell Univ/NY	981	9.27	Private
19	389	N Mex I Mining & Tech	33	9.17	Public
20	28	Princeton Univ/NJ	410	9.02	Private
21	222	Wabash College/IN	73	8.89	Private
22	140	Wesleyan Univ/CT	133	8.88	Private
23	127	Amherst College/MA	143	8.60	Private
24	208	Earlham College/IN	72	8.53	Private
25	578	Hampshire Coll/MA	20	8.37	Private
26	1	Calif, U-Berkeley	1,472	8.31	Public
27	27	Rensselaer Poly I/NY	368	8.24	Private
28	92	Polytechnic Univ/NY	210	8.10	Private
29	212	Bryn Mawr Coll/PA	75	7.90	Private
30	106	Brandeis Univ/MA	148	7.88	Private
30	56	John Hopkins U/MD	276	7.88	Private
32	89	Calif, U-Riverside	189	7.86	Public
33	10	Harvard Univ/MA	730	7.54	Private
34	138	Franklin & Marshall C/PA	134	7.19	Private
35	628	St Johns College/MD	18	7.17	Private
36	148	Wooster, Coll of/OH	119	7.03	Private
37	202	Kalamazoo College/MI	65	7.00	Private
38	24	Yale University/CT	470	6.88	Private
39	49	Carnegie-Mellon U/PA	277	6.83	Private
40	158	Calif, U-Santa Cruz	110	6.67	Public

Rank	B.A. to Ph.D. Rank	Institution	Total # S/E Ph.D.'s	Productivity Ratio	Type
41	43	Rochester, Univ of/NY	320	6.54	Private
42	38	Brown University/RI	321	6.50	Private
43	144	Williams College/MA	113	6.49	Private
44	293	Phila C Pharm & Sci/PA	52	6.42	Private
45	782	Webb I Naval Arch/NY	6	6.38	Private
46	185	Worcester Poly I/MA	93	6.29	Private
47	75	SUNY at Stony Brook	191	6.26	Public
47	19	Stanford Univ/CA	560	6.26	Private
49	33	Case Western Reserve/OH	399	6.24	Private
50	205	Bowdoin College/ME	77	6.20	Private
51	218	Knox College/IL	75	6.02	Private
52	200	Stevens Inst Tech/NJ	80	5.79	Private
53	220	Davidson College/NC	74	5.78	Private
54	35	Calif, U-Davis	337	5.73	Public
55	130	Union University/NY	144	5.72	Private
56	431	Eckerd College/FL	24	5.70	Private
57	8	Calif, U-Los Angeles	848	5.68	Public
58	532	Blackburn College/IL	21	5.65	Private
59	7	CUNY-City College	915	5.59	Public
60	245	Lawrence Univ/WI	69	5.51	Private
61	67	Dartmouth College/NH	235	5.45	Private
62	14	Columbia Univ/NY	646	5.44	Private
63	438	Delaware Valley C/PA	34	5.37	Private
64	261	Bates College/ME	62	5.35	Private
65	216	Beloit College/WI	72	5.33	Private
66	178	Clark University/MA	92	5.32	Private
67	375	Ill Benedictine Coll	25	5.31	Private
68	621	King College/TN	15	5.24	Private
69	275	Juniata College/PA	54	5.23	Private
70	156	Occidental Coll/CA	106	5.20	Private
71	129	SUNY at Binghamton	131	5.18	Public
72	95	Illinois Inst. Tech	187	5.15	Private
73	244	Muhlenberg Coll/PA	77	5.08	Private
74	164	Lafayette College/PA	117	5.06	Private
75	282	Whitman College/WA	52	4.99	Private
76	150	Wellesley College/MA	118	4.94	Private
77	147	Calif, U-Irvine	102	4.92	Public
78	271	SUNY Envr Sci Frstry	52	4.84	Public
79	82	Lehigh University/PA	190	4.78	Private
80	190	U.S. Military Academy	99	4.76	Public
81	310	Rhodes College/TN	41	4.71	Private
82	677	U.S. Merchant Mar Academy	18	4.69	Public
83	252	Hamilton College/NY	60	4.64	Private
84	281	Kenyon College/OH	40	4.63	Private
85	57	Duke University/NC	282	4.60	Private

Rank	B.A. to Ph.D. Rank	Institution	Total # S/E Ph.D.'s	Productivity Ratio	Type
86	497	Bard College/NY	20	4.58	Private
87	473	Centre Coll Kentucky	29	4.56	Private
88	206	Hope College/MI	74	4.53	Private
89	333	Lebanon Valley C/PA	45	4.52	Private
90	240	Colorado Sch Mines	55	4.47	Public
91	280	Drew University/NJ	51	4.40	Private
92	191	Vassar College/NY	92	4.33	Private
93	300	S. Dakota S Mine & Tech	45	4.31	Public
94	711	Pitzer College/CA	12	4.29	Private
95	21	Iowa State Univ	520	4.28	Public
95	483	Charleston, C of/SC	26	4.28	Public
97	266	Berea College/KY	61	4.26	Private
98	358	Cornell College/IA	38	4.21	Private
99	136	Bucknell Univ/PA	130	4.20	Private
100	204	Yeshiva Univ/NY	65	4.16	Private
100	229	Macalester Coll/MN	72	4.16	Private

Appendix C. — Science and Engineering Graduate Study and Credentials in Other Nations

The U.S. system of university-based graduate education, combining research and training, is admired throughout the world for the quality of researchers it produces. However, it is not the only model for training and certification of researchers. Other nations take different approaches to training graduate-level scientists and engineers for academic and industry research and development (R&D), reflecting major social, administrative, legislative, and economic differences in university systems, in where and how R&D is conducted and funded, and where scientists and engineers are employed in that country.[1] Higher education in other countries generally is more science- and engineering-intensive, particularly in Japan, Soviet Union, and West Germany.

There is no "best" model for graduate education. The U.S. university system is decentralized, with a large high-quality private sector; many other nations have much more centralized systems. Most developed countries have reformed university education in the past decade, often modeling U.S. successes. These reforms have been driven and accompanied by a move to mass higher education, problems of overexpansion in the face of declining young populations, worries about quality, and retrenching in tight budgets.

Japan.[2] Although Japan awards more science and engineering doctorates on a per capita basis than does the United States, far fewer of these are obtained through formal university graduate studies. Students follow two paths to the doctorate. Students may earn a "course doctorate" (*katei hakushi*) in one of the major universities, similar to the United States, with courses, 5 years or so of research, and an oral defense of the dissertation. Graduate students conduct research for their professor and do not serve as teaching assistants. These graduates usually stay in the universities after completion of the doctorate.

A greater number of "dissertation doctorates" (*ronbun hakushi*) are awarded not to graduate students, but to researchers who submit a dissertation based on research conducted outside the university. Many of these are industry employees, and their dissertation research usually is geared toward their industry work. Few academic Ph.D.s work in industry. Companies prefer to hire young, broadly-educated college graduates and train them (often sending them overseas for graduate training). Many complete graduate studies at the university, but do not receive a degree; some may later earn a "dissertation doctorate." Japanese institutions offer a 2-year master's degree, and, as in the United States, the number of students receiving this degree has grown rapidly. The Japanese are placing ever more importance on graduate education as a potential source of creative researchers for building industry R&D, and the Ministry of Education has announced expansion plans.

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[1] S. Blume and O. Amsterdamska, *Post-Graduate Education in the 1980s* (Paris, France: Organisation for Economic Co-operation and Development, 1987).

[2] Lawrence P. Grayson, "Technology in Japan, Part 1: Graduate Education," *Engineering Education*, April/May 1987, pp. 687-696; and William K. Cummings, "Japan's Science and Engineering Pipeline: Structure, Policies, and Trends," OTA contractor report, October 1987.

Parents are a more important source of financial support for graduate students in Japan than in other countries. Overall, about 40 percent of support comes from parents, about 30 percent from scholarships, and about 30 percent from job earnings.[3]

West Germany. The German doctorate is fairly similar to the U.S. Ph.D., although graduate training generally takes longer and involves more formal study and less independent research than in the United States. A graduate student may spend several years in formal studies, do a modest thesis, and then spend another 3 or 4 years on dissertation research. The doctorate recipient is often over 30, and may have spent time in military service or in industry. The *Doktor Habilitation* is a postdoctoral degree considered necessary for receiving an academic post. Compared to the United States, there are relatively few graduate students in West Germany.

In engineering, the *universitat* offers a 5-year *Diplome Ingenieur* (between a B.S. and a master's), which includes 1 year of work in industry. The average age of Dip. Ing. recipients is 25. While university training is preferred for research or academic engineers, most people working as production, design, or line engineers are trained through formal apprenticeships or have a 3- or 4-year engineering degree from a *Fachhochschule*, similar to British polytechnics or the best U.S. engineering technology programs. Graduate students and researchers come through the universities rather than the *Fachhochschulen*.[4]

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3. Blume and Amsterdamska, op. cit, footnote 1, p. 32.

4. Lawrence P. Grayson, "EE Education Around the World," *IEEE Spectrum*, November 1984, p. 66; and Joseph Mintzes and William Tash, *Comparison of Scientific and Technical Personnel Trends in the United States, France, West Germany, and the United Kingdom Since 1970*, NSF 84-335 (Washington, DC: National Science Foundation, 1984), pp. 147-157.

Great Britain. The university D. Phil. is awarded earlier in Great Britain than in the United States, at age 25 or 26, usually after 3 years of study (beyond a 3- or 4-year undergraduate course). With necessary coursework, this leaves little time for research. The universities are primarily government-supported and essentially all students are supported by nontaxable government studentships, and thus are less tied to fluctuating university needs for teaching and research assistants. Great Britain also has a large polytechnics and colleges sector geared to undergraduate education, including engineering.

France. French universities are centralized and government-supported. Students often hold teaching or research assistantships. Graduate education and college education are quite different and are less distinct in France than they are in the United States (and secondary education extends slightly longer in France); "graduate" education really consists of the latter years of higher education. Following 2 years of general study and 2 years of specialized study leading to a maîtrise or an engineering degree, or to a university *Diplome d'Etudes* (between a bachelor's and a master's), graduate-level scientists and engineers can follow two paths: entry to the small and prestigious Grand Écoles, which concentrate on engineering, applied sciences, and technical management; or the entry into universities, which enroll the vast majority of students and have a longer and broader curriculum.

The Grandes Ecole degree, the elite *Diplome d'Ingenieur*, is roughly equivalent to a U.S. master's of engineering management. It is essentially all formal classroom learning (most students spend a few months in work assignments out of 5 years), and is general rather than technically specialized. Those few graduates of the Grandes Écoles who go into research (rather than industry or government) often go to university laboratories for several more years of thesis research, and may receive the doctorate.

The main route of advanced study used by most science students is through the universities. Following recent, politically-charged reform, the several doctorate level degrees (*Ingenieurs Docteur*, individual university doctorates awarded mostly to foreigners, *Troiseme* cycle doctorate, and the high-level pinnacle of the *Doctorate d'Etat*, awarded after the *Troiseme* and important for an academic career) were combined into one doctorate requiring 2 to 4 years of additional study, similar to the British Ph.D. In addition, a degree similar to the German *Habilitation* is now awarded in place of the *Doctorate d'Etat*, recognizing advanced research and achievement.[5]

Italy. Italy has no research-oriented Ph.D.-like degree beyond the *Laurea*, a master's level degree usually awarded around age 23. At some point, aspiring faculty members can obtain a title of *Docent* based on their academic achievements, as demonstrated by publications and prepared lectures.

China. China is rapidly rebuilding the infrastructure of research and graduate education that was disrupted by the Cultural Revolution. Universities, colleges, and institutions for engineering and other specialities are examined, authorized, and funded by the state, although many are run by local governments. Graduate enrollments are approved by the state as part of national planning, although universities are being given more discretion in their admissions, hiring, promotion, and spending. Entry, until recent experimental reforms, has been by competitive examination. Universities require about 2½ years of study for a master's degree, a year of which is research. A doctorate takes 3 more years, all devoted to research except for one semester.[6] About 660 doctorates were awarded in all fields in 1987, and over 53,000 master's.[7] New policies encourage part-time graduate study for students with 2 or more years of work experience, and new graduate students to spend a year working before pursuing academic study. Most doctorates go into university teaching to help the country expand higher education, particularly in science and engineering.

Soviet Union.[8] In the Soviet Union, research is concentrated in a few government-run institutes and a few of the leading universities which conduct significant amounts of quality research. Thus many university students do not get intimately involved in research. Universities and various technical institutes (*VUZy*) are concentrated in a few cities. Approximately 40 percent of Soviet graduate students earn their degrees at scientific research institutes and institutions of the Academy of Sciences rather than at *VUZy*.

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[5] Guy R. Neave, "Science and Engineering Work Force Policies: Western Europe," OTA contractor report, September 1987, p. 11.

[6] Richard DeMeis, "Engineers for China's Future," *Aerospace America*, January 1988, pp. 7-9, 56.

[7] Meng Yang, "Developments and Reform in Graduate Education in the PRC," *Graduate Education — Communities of Scholars*, Proceedings of the Twenty-Seventh Meeting of the Council of Graduate Schools, Washington, DC, December 1-4, 1987, p. 44. See also Halsey L. Beemer, Jr., "Chinese Engineering Education: The Development of Graduate and Undergraduate Studies," *Graduate Education — Communities of Scholars*, Proceedings of the Twenty-Seventh Meeting of the Council of Graduate Schools, Washington, DC, December 1-4, 1987, pp. 48-57.

[8] Harley D. Balzer, "Soviet Science and Engineering Education and Work Force Policies: Recent Trends," OTA contractor report, 1987.

There are two major advanced degrees: Candidate of Science (*kandidat nauk*) and Doctor of Science (*Doktor nauk*). The *kandidat* degree is closest to the American Ph.D., although may require less work. There is no direct equivalent of a master's. The *kandidat* recipient is generally earned by younger scholars who have completed their initial period of mandatory employment following graduation from a *VUZy*. (In unusual cases, a promising student may be permitted to continue study immediately following graduation.) Most graduate students at *VUZy* have been sent by their employers, with the expectation that they will return after completing their degrees. All graduate students are, of course, state-supported, and receive a modest stipend. The Soviet *Doktor* degree often honors a senior scholar who has already achieved significant status, and is awarded as much for the corpus of work as for a specific dissertation. Most Soviet Doctors of Science are at the level of full professors in American universities.

Soviet reforms are geared toward fostering research creativity and innovation: encouraging early involvement in research, encouraging more students to continue toward advanced degrees without interruption, awarding the *kandidat* degree for "practical" work, and offering greater recognition for outstanding students and faculty.

Natural Science and Engineering (NSE) Doctorate-Level Degrees For Selected Nations, 1984

	No. NSE Ph.D.s	NSE Ph.D.s as % of 27-year olds	Ratio of 1984 NSE Ph.D.s to 1980 NSE B.S. Degrees[a]
U.S. (1985)	12,101	0.3	7
Japan	2,712	0.2	3
West Germany	4,650	0.5	31
France[b]	4,800	0.6	22
U.K.	3,846	0.5	12

NOTE: NSE includes agriculture but not the social sciences.

[a] The French degree includes the *Troiséme* cycle and *Docteur Ingenieur* degrees, which are somewhat less than a Ph.D., and the *Docteur d'etat*, which is more than a Ph.D. France will grant one Ph.D.-level doctorate in the future.

[b] Ph.D. data (numerator) from National Science Foundation, *International Science and Technology Update*, NSF 87-319 (Washington, DC: 1987); B.S. data (denominator) from National Science Board, *Science Indicators: The 1985 Report*, NSB 85-1 (Washington, DC: 1986), p. 192.

SOURCE: National Science Foundation, *International Science and Technology Update*, NSF 87-319 (Washington, DC: 1987), pp. 38, 42.

Appendix D. — A Chronology of Reports on Engineering Education

1918 Publication of the Mann Report, *A Study of Engineering Education*, sponsored by the Society for the Promotion of Engineering Education (SPEE) and funded by the Carnegie Foundation. It urged: return to fundamentals and unify fragmenting curricula; merge theory and practice in coursework; introduce "real work," including "values and costs," into teaching engineering problem solving; retain shop experience, laboratory, industrial training, cooperative and summer work in curriculum; English mastery; link technology to its human and social setting; closer university-industry linkage, especially in research, to improve productivity and thereby national well-being; develop discipline for work and "lifelong" study; select faculty based on teaching ability and work experience, not just research excellence.

1930 Publication of volume 1 of the Wickenden Report, *Report of the Investigation of Engineering Education 1923-1929*.

1934 Publication of volume 2 of the Wickenden Report. It urged a halt to fragmentation of curricula; graduate engineering education and continuing education for 5 years after graduation; forms of technical education other than engineering colleges; functional rather than professional engineering education; design project, including writing, for second and third year students; third year project teaching, fourth year honors option; stronger high school preparation; lifetime learning in cooperation with industry; professional certification by engineering societies independent of State licensing; higher faculty standards; teach engineering method; teach society and values so engineers can understand social impact of engineering.

1939 H.P. Hammond Report for SPEE, *Aims and Scope of the Engineering Curriculum*, recommended: diversification of curricula; parallel technical and humanities/social sciences "stems"; reconsideration of 4-year curriculum and move to 5- or even 6-year program.

1944 H.P. Hammond Report for SPEE Committee on Engineering Education After the War: reaffirmed 1939 report; promoted expanding technician programs to fill industrial needs then being met, non-optimally, by engineers; and teaching the "art" of engineering as distinct from scientific method.

1955 L.E. Grinter, *Report on the Evaluation of Engineering Education* for American Society for Engineering Education (ASEE). The final report included comments by 122 engineering colleges. It recommended: five "stems" — humanities and social sciences, mathematics and basic science, generic engineering science, engineering specialty subjects, and electives; a two-track undergraduate curriculum, one to immediate employment, the other to graduate study; twin goals for engineering education — technical (analysis and "creative design"; construction, production, operation) and social (ethics, general education, leadership in technological action); improved high school preparation and articulation with admission standards; the integration of graduate education and research-oriented faculty into undergraduate curriculum; requirements for industrial experience and proven teaching ability for tenure; programs for gifted students; improved facilities; dropping shop and upgrading laboratories, retaining a 4-year curriculum but encouraging experimentation; a focus on design; a base curriculum of engineering science, not contemporary engineering practices; the inclusion of social and economic factors in solutions to technological problems; unification of analytical methods in all branches of engineering; and lifelong learning.

1956 Publication of the E.S. Burdell Report, complementary to the Grinter Report, *General Education in Engineering — Report of the Commission for the Humanities: Social Research Project* (of the ASEE). Conclusions: more humanities and social sciences needed; rejected fears that this will either weaken engineering education or lead to superficial treatment of humanities and social sciences.

1959 Report to President Eisenhower by Lee DuBridge, Chairman of the President's Science Advisory Committee, *Education for the Age of Science* urged: enhance the image of the teaching profession; improve high school education as preparation for science and engineering careers; reform curricula by unifying it along scientific principles common to engineering specializations, teach relation of engineering to social and governmental problems instead of parallel humanities/social sciences stem; promote the Ph.D. for engineers;

provide special programs for gifted students; expand technical institutes; and retain faculty.

1966 Engineers Joint Council response to Interim ASEE *Goals of Engineering Education* Report: integrate teaching of engineering practice into its social context; focus on fundamentals, not current information; do not standardize curricula or accreditation; increase student-faculty interaction; promote lifetime learning; and expand the role of engineering professional societies in linking education to state-of-the-art practices.

1968 Publication of Final Report of the 5-year ASEE study, *Goals of Engineering Education*. It endorsed the Grinter Report on engineering science as the basis of engineering education. Recommendations: add 1 year of graduate study to basic engineering education; limit prerequisites and open the engineering major to transfers; expand cooperative and interdisciplinary programs; reduce credit hours for graduation; improve teaching of social and economic factors influencing, and influenced by, technology by integrating humanities and social sciences into the engineering curriculum; integrate research and undergraduate teaching; hire faculty with industrial experience, regardless of degrees; expand technician programs; and expand industry funding of engineering research; promote advanced engineering education (Ph.D.), continuing education, lifelong learning, professional registration by faculty. Predictions: M.S. will become the basic engineering degree; fewer programs/institutions; and the increasing use of engineering to solve social problems.

1968 Olmsted Report for ASEE: integrate humanities and social sciences into 4-year programs; improve general education; retain humanities and social science faculty; and reduce the number of electives while retaining breadth.

1975 The Massachusetts Institute of Technology Center for Policy Alternatives Report, J. Herbert Holloman, Chairman, *Future Directions for Engineering Education: System Response to a Changing World*, provoked by a "precipitous decline" in engineering enrollments and America's global dominance. It noted that engineering education was too responsive to "transient" changes. Recommended: prepare for declining enrollments; restore art of engineering to curriculum by teaching design; require work experience or cooperative education; integrate humanities and social sciences into engineering curriculum; raise consciousness of "culture" of the sciences as opposed to their techniques; teach social, economic, political and legal constraints on engineering; expand 2- and 4-year technology programs; promote continuing education in engineering rather than management; expand evaluation; promote the engineering major as generic preprofessional training; and use industry more as a resource and sponsor.

1982 *The Quality of Engineering Education*, National Association of State University and Land-Grant Colleges, J. D. Kemper, Chairman. Cited problems of overenrollment, faculty shortages, and serious inadequacies in equipment, space, and facilities; and recommended increased faculty salaries and industry support and government funding to upgrade the infrastructure.

1985 The National Academy of Engineering (NAE) publishes a 9-volume study, *Engineering Education and Practice in the U.S.*, chaired by J.A. Haddad.

1985 NAE report to the National Science Foundation (NSF), *New Directions for Engineering in the NSF*, Peter Likins, Chairman.

1986 National Conference on Engineering Education, convened by the Accreditation Board for Engineering and Technology. Consensus recommendations: update undergraduate engineering education with mathematics concentration in probability, statistics, and numerical analysis; more breadth in basic sciences; expand humanities, social sciences, and communication skills; focus on design, including socioeconomic factors; intensify use of computers; introduce interdisciplinary coursework in real-world problem contexts; set admission standards that obviate need for remediation; strengthen faculty, requiring industrial experience and teaching effectiveness for tenure; continuing education; advisory committee of practicing engineers for each engineering education unit; raise fellowship stipends to one-half industry starting salary to attract U.S. graduate students; tighten the link of engineering education to engineering practice; encourage longer than 4-year curricula but do not mandate them; and increase role for engineers vis-a-vis executives, economists, and politicians in improving competitiveness.

1986 Final ASEE Report, *Quality in Engineering Education Programs*, W. Edward Lear, Project Director. Cited problems of overenrollment, insufficient and obsolete laboratory equipment, and facilities shortage and deterioration. Recommeded: re-emphasize production along with research; make industrial experience and effective teaching conditions of tenure; require test of spoken English for teaching assistants; institute structured continuing faculty education; implement computers and other new educational technologies; expand production of technicians; and improve laboratory teaching, assigning senior faculty to it.

1986 *The Quality of Engineering Education II*, followup to 1982 report, James E. A. John, Chairman. Recommended: promote U.S. citizen graduate study by raising fellowship stipends to one-half industry starting salary; fund large scale facilities improvement and maintenance; retain Ph.D. faculty with a healthy campus research environment; and produce more technicians.

1986 National Academy of Engineering, *The Impact of Defense Spending on Nondefense Engineering Labor Markets*.

1986 *Engineering College Research and Graduate Study: A 20 Year Statistical Analysis*, W.J. Fabricky, J.E. Osbourne and R.C. Woods.

1987 ASEE Report, *A National Action Agenda for Engineering Education*, E. E David, Chairman. Its eight recommendations: scale back the 4-year, necessarily limited curriculum to prepare for continuing education; make graduate education more practice-oriented; re-emphasize engineering design and manufacturing; improve undergraduate laboratories; attract more and better U.S. graduate students and faculty with higher salaries and research funding; bolster faculty development; support career-long education; and improve precollege mathematics and science education and introduction to engineering careers.

SOURCE: Steven L. Goldman, "The History of Engineering Education: Perennial Issues in the Supply and Training of Talent," OTA contractor report, 1987.

Appendix E — Contractor Reports

Full copies of Contractor Reports done for this project are available through the National Technical Information Service (NTIS), either by mail (U.S. Department of Commerce, National Technical Information Service, Springfield, VA 22161) or by calling them directly at 703/487-4650.[1]

Higher Education (NTIS order #PB 88-177 951/AS)

1. "The Apollo Program: Science and Engineering Personnel Demand Created by a Federal Research Mission," Arnold S. Levine, Consultant
2. "Institutional Productivity: The Undergraduate Origins of Science and Engineering Ph.D.s," Betty D. Maxfield, Consultant
3. "The History of Engineering Education: Perennial Issues in the Supply and Training of Talent," Steven L. Goldman, Lehigh University

Elementary and Secondary Education (NTIS order #PB 88-177 944/AS)

1. "Images of Science: Factors Affecting the Choice of Science as a Career," Robert E. Fullilove, University of California, Berkeley
2. "Identifying Potential Scientists and Engineers: An Analysis of the High School-College Transition," Valerie E. Lee, University of Michigan

International Comparisons (NTIS order #OB 88-177 969/AS)

1. "Japan's Science and Engineering Pipeline: Structure, Policies, and Trends," William K. Cummings, Harvard University
2. Soviet Science and Engineering Education and Work Force Policies: Recent Trends," Harley Balzer, Georgetown University

Funding for Higher Education: Part I (NTIS order #PB 88-177 928/AS)

1. "Federal Funding of Science and Engineering Education: Effect on Output of Scientists and Engineers, 1945-1985," Betty M. Vetter, Commission on Professionals in Science and Technology, and Henry Hertzfeld, Consultant
2. "Science in the Steady State: The Changing Research University and Federal Funding," Edward J. Hackett, Rensselaer Polytechnic Institute

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[1] Guy R. Neave's report, "Science and Engineering Work Force Policies: Western Europe," is only available through the Science, Education, and Transportation Program office 202/228-6920.

Funding for Higher Education: Part II (NTIS order #PB 88-177 936/AS)

1. "Industrial Support of University Training and Research: Implications for Scientific Training in the 'Steady State," Michael E. Gluck, Harvard University

2. "Financial Assistance, Education Debt and Starting Salaries of Science and Engineering Graduates: Evidence From the 1985 Survey of Recent College Graduates," Applied Systems Institute, Inc., Richard Wabnick (Principal Investigator)

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